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Research Paper

Phenotypic stability, genotype × environmental interactions, and cultivar recommendations for essential oil yield in khus aromatic grass (*Chrysopogon zizanioides (L.)* Roberty)

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ABSTRACT

The study was carried out to predict yield stability of the sixty vetiver accessions using various parametric/non-parametric statistics over two years. The pooled ANOVA and AMMI analysis expressed that environments/years (E), genotypes/accessions (G), and genotype × environment/years (G × E) interaction were highly significant, indicated that the accessions interacted differentially with different years. Therefore, it is imperative to that stability/adaptability analysis across the environments/years should be followed before the recommendation for commercial cultivation in any crops. Based on the stability analysis using AMMI model, accessions G-10, 23, 38 and 40 showed the widest adaptability/stability due to its ability to tolerate wide environmental conditions over years. Thus, these accessions can be recommended as the most stable accessions for cultivation for wide areas.

1. Introduction

Vetiver/khus (*Chrysopogon zizanioides* (L) Roberty formerly *Vetiveria zizanioides* (L.) Nash, family-Poaceae) is India's most important aromatic essential oil producing plant, comprising nearly 10,000 ha area grown/under cultivation. Vetiver is a perennial aromatic grass which originated in India. It is cultivated for the essential oil extracted from its roots, which spread a pleasant aroma with different notes like earthy, saffron, turmeric, Cyprus, grapefruit, rosy, flowery, etc. depending upon its oil quality and origin (Virmani and Datta, 1975; Lal et al., 1998; Gupta et al., 2015).

The plant transcriptome (Kravchik and Bernstein, 2013) and consequently the production of secondary metabolites in plants are well known to be affected by environmental conditions (Gorelick and Bernstein, 2014). Alteration in environmental conditions can therefore be applied to regulate production of secondary metabolites in medicinal and aromatic plants (Sathiyabama et al., 2016). Production of essential oil is known to vary also between varieties and accessions within the same species (Ivanka et al., 2016; Fatih et al., 2016).

Moreover, vetiver oil is a highly valued basic ingredient of modern perfumery. Vetiver cultivation is most suited on the banks of rivers and coast line of the country which together amounts to approximately 20000 km. This provides the opportunity of cultivation of vetiver in approximately minimum 20000 ha. Currently, India is importing about 70–80 t vetiver oil per annum. The total world production of vetiver/khus essential oil is estimated to be 300–350 t per year as compared to 100 t produced annually in India. Therefore, khus cultivation in Indian context seems to be profit-driven with increasing oil demand for perfume and soap industries. However, the issues related to its relatively longer duration for maturity, non availability of stable oil producing varieties, digging of roots and poor yields have hindered its acceptance among the farmers. Due to the unavailability of sandalwood oil for a variety of perfumes, vetiver oil is being used increasingly and hence, its demand is continuously on rise. However, there exists ample scope for India becoming the leading exporter of vetiver oil in another few years with a possibility of exporting vetiver oil at least to the tune of Rs 200–300 crores per annum (Gupta et al., 2015; Lal, 2012). CSIR-CIMAP's technological interventions have led to the release of nine khus cultivars for maximizing the benefits of khus growers in India. Development of short-duration (10–12 months) and high-yielding cultivars like Dharini, KS-1, KS-2, Gulabi and CIM-Vridhi has attracted large number of farmers of UP, Bihar, Punjab, Chhattisgarh, Jharkhand,

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Table 1
Pooled ANOVA over years for the sixty accessions of Vetiver.

Source of variations	d.f.	Mean sum of squares (m.s.s.)			
		Characters			
		Plant height (mts)	Root yield/ plot (g)	Essential oil contents (%)	Essential oil yield/ plot (g)
Replications	2	0.022	1670.000	0.005	0.111
Treatments	119	0.048**	28136.030**	0.477**	9.470**
Accessions	59	0.058*	27320.750**	0.665**	11.296**
Year	1	0.026**	9616.000**	0.147**	13.844**
Accessions × Year	59	0.040**	29742.030**	0.305**	7.731**
Error	238	0.013	3958.319	0.011	0.379
Total	359				

*−p < 0.05, **−p < 0.01, respectively.

Karnataka and Odisha states in recent years (Singh et al., 2005; Lal et al., 1998). Besides, CIM-Khusinolika, a six months duration crop, has shown the potential to further enhance the income and cultivation of farmers and to meet out the requirement of perfumery industry (Chauhan et al., 2017). In India khus cultivation gives a net profit of over Rs 1.5 lakh in a span of 10–12 months with 25–30 kg/ha oil yield. In addition, co-cultivation of khus with wheat, lentil, peas, mint, basil etc. brings an additional profit of about Rs. 30,000/ha (Lal et al., 1998; Patra et al., 2005; Singh et al., 2005; Lal, 2012).

The Yield of each vetiver accessions in each test year/environment is a mixture of environment/year main effect (E), genotype/accessions main effect (G) and genotypes/accessions × environment (G × E) interaction. Moreover, G and its other components environment/year main effect (E) and genotypes/accessions × environment (G × E) interaction must be considered simultaneously when making accession selection decisions (Gupta et al., 2015). Looking at the large quantities of vetiver essential oil still imported, there is a need to further enhance the area under khus cultivation, by popularizing high oil yielding and early maturing stable varieties of this crop. Studies of genotypes by environment interactions (G × E) and stability have been reported very meager on vetiver crop. However, no stability and reliability studies have been performed/tested over year trial for good quality vetiver essential oil. The objectives of present study were to evaluate the essential oil yield of sixty accessions in two consecutive years in India and to determine their stability for essential oil yield and cultivar recommendations.

2. Materials and methods

In order to identify stable and high performance accessions of vetiver, the sixty vetiver accessions from indigenous and exotic collections of vetiver (*Chrysopogon zizanioides*, Roberty), related to thirteen states of India (Uttar Pradesh, Uttaranchal, Rajasthan, Bihar, Punjab, Madhya Pradesh, Gujarat, Delhi, Jammu and Kashmir, Odisha, Maharashtra, Kerala, Andhra Pradesh) and four exotic collections from Indonesia, Haiti, Thailand and Reunion Island used for the present investigation. They were evaluated at the Research Farm of CSIR-Central Institute of Medicinal and Aromatic Plants, P.O. CIMAP, Lucknow, U.P. 226 015 (India)-in the two consecutive years: 2014–2015 and 2015–2016 in a randomized complete block design with three replications. The experimental field of the farm was situated at 26.5 °N latitude; 80.50 °E longitude; 120 m above mean sea level. The overall climate is semiarid-subtropical in nature. The environmental conditions during the two cultivation years as minimum and maximum night and day temperatures ranged 25–30 °C to 35–45 °C, respectively during growth period and from, 8–11 °C to 15–17 °C, respectively, during harvesting time. Average rainfall during the growing season was 10–15 mm in the year 2014-15 and the minimum and maximum night and day temperatures ranged 28–35 °C to 39–46 °C, respectively during growth period and from, 5–12 °C to 14–18 °C, respectively, during harvesting time. Average rainfall during the growing season was 9–12 mm in the year 2015-16 according to weather data of the Metrological Laboratory of

Table 2
Genotype/clones means for AMMI I (grand mean = 9.786) essential oil yield (g/plant) in vetiver.

S.No	Genotypes	Mean	Count	Index	Name	Mean	S.No.	Genotypes	Mean	Index	Name	Mean
1.	Veti-1	1.967	2	7	Veti-7	12.150	31.	Veti-31	3.750	3	Veti-3	3.667
2.	Veti-2	3.417	2	51	Veti-51	11.733	32.	Veti-32	4.750	26	Veti-26	3.617
3.	Veti-3	3.667	2	56	Veti-56	9.067	33.	Veti-33	4.667	57	Veti-57	3.583
4.	Veti-4	1.217	2	38	Veti-38	8.850	34.	Veti-34	4.400	24	Veti-24	3.500
5.	Veti- 5	0.933	2	23	Veti- 23	8.667	35.	Veti-35	3.333	2	Veti-2	3.417
6.	Veti- 6	4.583	2	40	Veti- 40	8.167	36.	Veti-36	3.867	46	Veti-46	3.417
7.	Veti- 7	12.150	2	60	Veti- 60	8.000	37.	Veti-37	4.500	35	Veti-35	3.333
8.	Veti- 8	0.733	2	10	Veti- 10	7.500	38.	Veti-38	8.850	59	Veti-59	3.300
9.	Veti- 9	5.083	2	9	Veti- 9	5.083	39.	Veti-39	3.000	55	Veti-55	3.250
10.	Veti- 10	7.500	2	42	Veti- 42	5.000	40.	Veti-40	8.167	25	Veti-25	3.150
11.	Veti- 11	4.167	2	12	Veti- 12	5.000	41.	Veti-41	3.117	28	Veti-28	3.133
12.	Veti −12	5.000	2	49	Veti −49	4.867	42.	Veti-42	5.000	41	Veti-41	3.117
13.	Veti- 13	2.700	2	32	Veti- 32	4.750	43.	Veti-43	3.917	47	Veti-47	3.083
14.	Veti- 14	4.367	2	44	Veti- 44	4.700	44.	Veti-44	4.700	18	Veti-18	3.083
15.	Veti- 15	3.083	2	33	Veti- 33	4.667	45.	Veti-45	4.000	15	Veti-15	3.083
16.	Veti-16	2.833	2	6	Veti-6	4.583	46.	Veti-46	3.417	39	Veti-39	3.000
17.	Veti-17	3.750	2	50	Veti-50	4.567	47.	Veti-47	3.083	27	Veti-27	2.833
18.	Veti-18	3.083	2	37	Veti-37	4.500	48.	Veti-48	3.833	20	Veti-20	2.833
19.	Veti-19	3.917	2	34	Veti-34	4.400	49.	Veti-49	4.867	16	Veti-16	2.833
20.	Veti-20	2.833	2	14	Veti-14	4.367	50.	Veti-50	4.567	13	Veti-13	2.700
21.	Veti- 21	2.583	2	54	Veti- 54	4.333	51.	Veti-51	11.733	53	Veti-53	2.667
22.	Veti-22	1.883	2	11	Veti-11	4.167	52.	Veti-52	2.500	21	Veti-21	2.583
23.	Veti-23	8.667	2	45	Veti-45	4.000	53.	Veti-53	2.667	52	Veti-52	2.500
24.	Veti-24	3.500	2	19	Veti-19	3.917	54.	Veti-54	4.333	1	Veti-1	1.967
25.	Veti-25	3.150	2	43	Veti-43	3.916	55.	Veti-55	3.250	22	Veti-22	1.883
26.	Veti-26	3.617	2	36	Veti-36	3.867	56.	Veti-56	9.067	29	Veti-29	1.383
27.	Veti-27	2.833	2	48	Veti-48	3.833	57.	Veti-57	3.583	4	Veti-4	1.217
28.	Veti-28	3.133	2	17	Veti-17	3.750	58.	Veti-58	3.667	5	Veti-5	0.933
29.	Veti-29	1.383	2	31	Veti-31	3.750	59.	Veti-59	3.300	8	Veti-8	0.733
30.	Veti-30	0.600	2	58	Veti-58	3.667	60.	Veti-60	8.000	30	Veti-30	0.600