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Genetics of essential oil yield and their component traits in vetiver (*Chrysopogon zizanioides* (L.) Roberty)

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Abstract

The thirteen lines and five testers used for Line × tester analysis in vetiver (*Chrysopogon zizanioides* (L.) Roberty) to estimate the general and specific combining ability and the other allied genetic parameters with respect to physiological traits, essential oil contents, yield of essential oil and other components. The mean squares of all the eleven traits were significant for variances GCA and SCA stipulating that additive and non-additive genes control these characters. The character root yield/plot (ml), female lines L4 (g.c.a.= 71.585, $\bar{x}$/Mean= 553.33), L13 (g.c.a.= 63.918, $\bar{x}$/Mean= 383.33), and among testers T3 (g.c.a.= 31.149, $\bar{x}$/Mean= 583.33) followed by T1 (g.c.a.= 26.046, $\bar{x}$/Mean= 433.33) were the better general combiners; In the essential oil trait the female lines L1 (g.c.a.= 0.240, $\bar{x}$/Mean= 0.80) followed by L3 (g.c.a.= 0.143, $\bar{x}$/Mean= 0.81), L2 (g.c.a.= 0.111, $\bar{x}$/Mean= 0.85), L9 (g.c.a.= 0.203, $\bar{x}$/Mean= 0.78) were the better general combiners. For the character the essential oil/plot (g) the female lines L10 (g.c.a.= 1.156, $\bar{x}$/Mean= 0.97), L7 (g.c.a.= 0.869, $\bar{x}$/Mean= 3.50), L11 (g.c.a. = 0.802, $\bar{x}$/Mean=5.00), L9 (g.c.a.= 0.669, $\bar{x}$/Mean= 1.67), and L2 (g.c.a. = 0.556, $\bar{x}$/Mean=2.57), and among testers T3 (g.c.a.= 0.391, $\bar{x}$/Mean= 4.67) and T4 (g.c.a.=0.330, $\bar{x}$/Mean=5.67) were the better general combiners. The heritability in the narrow sense was low in all the traits (008-3.796 %) and in most of the traits genetic advance was poor (0.008-2.93) except the two traits i.e. high namely root yield/plot (ml) 180.44 and stomatal conductance (160.99) %. The relative magnitude of SCA variance was higher than GCA for all the traits in the present investigation, depicting the predominance of non-additive gene action for inheritance of these characters. The hybrids $L_7 \times T_3$ followed by $L_{10} \times T_5$, $L_2 \times T_3$ and $L_4 \times T_5$ were best for the essential oil yield of better quality and the three hybrids showed high mean performance for the khusimol content (%) namely, L8 × T4 (34.50), L3 × T1 (34.30) and L13 × T4 (34.17) % with high s.c.a. could be exploited for large area cultivation.

Keywords: Additive, combining ability estimates, line × tester analysis, non-additive, vetiver

1. Introduction

Chrysopogon zizanioides Roberty (Vetiver), (2*n*=20), Poaceae family, The vetiver is native to India. Vetiver roots are the main source of vetiver essential oil that has substantial value in pan masala, tobacco, perfumery, and essential oil industries. Perhaps no aromatic plants except rose, geranium, and sandal have good perfumery utility with comparison to the vetiver. In India, It grows wildly in many parts of India. The vetiver essential oil production is around 300-350 tons per year in the world. Approximate 100-150 tons of essential oil is annually produced in India, which is too low to cover the national and international demand for perfumes, tobacco, and essential oil industries. North India vetiver oil quality is best in the world. The Research Institute for Fragrance Materials has published a book on the essential oil quality of vetiver (Oyen and Dung, 2008) [17].

Vetiver is cultivated in more than a hundred countries to it's to prevent water/soil erosion, carbon sequestration, and water conservation. The vetiver roots are used for making handicrafts, toys, cooling khus-tatties in India. The vetiver essential oil also has many medicinal uses such as stomachic, refrigerant, diaphoretic, sudorific, emmenagogue, carminative, tonic, antispasmodic, anthelmintic, and diuretic, etc. The vetiver green leaves are also used as fodder of its high nutritive value (Husain amd Sharma, 1983; Brownstein. 1993; Lal *et al*., 1998; Lal *et al*., 2018a; Lal *et al*., 2020) [3, 1, 14, 10, 12].

The CSIR-CIMAP, Lucknow, C.S.A. University of Agriculture and Technology, Kanpur, and NBPGR in India has developed and released several hybrids and clones varieties of vetiver for examples K-1, K-2, K-3, Pusa hybrid 1, Pusa hybrid 2, KS-1, KS-2, CIM-Khus-15, CIM-Khus-22, KS-40, Sugandha, CIM-Vriddhi, Dharini all Khus odor, Gulabi (Rose odor), Kesari (Saffron odor), CIM-Khusnolika (Khusinol odor) and CIM-Samraddhi (Khusilal and Khushol rich) with fruity/blossom notes (Lal *et al*., 1998; Lal *et al*., 2020) [14, 12]. The CSIR-CIMAP, Lucknow, India is maintaining 165 accessions of khus/vetiver, representative the thirteen states, namely Madhya Pradesh, Uttar Pradesh, Bihar, Uttranchal, Odisha, Rajasthan, Jammu and Kashmir, West Bengal, Punjab, Gujarat, Delhi, Maharashtra, Kerala and Andhra Pradesh in India and four from Reunion Island, Haiti, Indonesia, and Thailand. There is the further possibility of the development of high root and better quality essential oil yielding varieties through use of the genetic diversity and hybridization, especially using line × tester design in this crop, Genetic improvement has been tried through line × tester design in the vetiver. The hybrids can yield about 20-25% more essential oil than the parents and the existing varieties of vetiver.

The combining ability concept is important for any plant breeding program; it is useful to the estimate of lines performance in the hybrids. For hybridization the knowledge of combining ability is very useful in choosing good parents. It is also useful to understand the inheritance pattern of quantitative traits and selecting the hybrids for utilizing in a breeding program. Thus, because of the combining ability importance and estimation of various genetic parameters, the line × tester design was applied to different economic traits in vetiver.

2. Materials and methods

Using line × tester mating design the sixty-five F_1 hybrids were developed by 13×5 females × five males. All lines and testers are fertile seed-producing parents. These hybrids including parents were grown in the research experiments at the research farm of CSIR-CIMAP, P.O. CIMAP, Lucknow U.P. (India) in a Randomized Block design replicated thrice with plot size=1.95m^2. The 5 irrigations and fertilizers: 120 kg N, 80 Kg P_2O_5, and 40 Kg K_20 were given during the whole crop span.

2.1 Metric observations

The metric observations were taken on 7 characters: plant height (m.), photosynthesis rate/net CO2 assimilation rate (u mol m^{-2} s^{-1}), transpiration rate (mmol m^{-2} s^{-1}), stomatal conductance (mmol m^{-2} s^{-1}), fresh root yield/plot (g), essential oil content (%), essential oil yield/plot (ml), khusimol content (%), khusinol content (%), α-vetivone content (%) and β-vetivone content (%).

2.2 Statistical analysis

The variance due to the GCA and SCA, and effects, ANOVA, and other genetic parameters were worked out by line × tester (L×T) design (Kempthorne, 1957) [5] using CIMAP-statistical software version 4.0 available at the Institute based on Singh and Choudhry (1914).

2.3 Distillation of essential oil

The fresh roots were distilled for the essential oil by hydro-distillation (Clevenger 1928) [2] for 24 hours. The extracted essential oils were kept at 4ºC prior to analysis. The essential oil was measured from Clevenger apparatus and essential oil content (%) was measured as volume (ml) of essential oil per 100 g of roots of vetiver.

2.4 Gas Chromatography (GC) and G-C Mass spectrometry analysis

GC and GC-MS analyses were performed as per our reported method (Pragadheesh *et al*. 2015) [19]. The relative retention index was calculated by injecting a homologous series of *n*-alkanes (C_6-C_{28} hydrocarbons, Polyscience Corp. Niles IL). Compound identification was achieved by recording NMR experiments, comparison of MS libraries (TurboMass NIST 2011 version 2.3.0 and Wiley registry of mass spectral data 9th edition), and reference guide on large-scale spectral data.

3. Results

The treatments, hybrids, parents, lines, and L×T mean square (MS) were found highly significant for all the characters. The testers were also significant for all except the photosynthesis rate and essential oil content characters (Table 1). However, parents × hybrids were also significant for all the traits except plant height (m), photosynthesis rate, transpiration rate, and essential oil content (%), respectively (Table 1). This is the clear cut indications of the presence of high genetic variability among lines, testers, and its hybrids in all the studied traits. Hence, the significance of GCA also indicated that the variations (additive/non-additive) were present in the characters. These gene actions were highly influential and control most of the traits.

The significance of variances due to GCA and SCA as it was evident from mean squares of all the eleven traits indicating the additive/non-additive genes controlled the characters; here the non-additive genes were more important than the additive genes because variance due to SCA was greater than GCA. The genes related to dominant were more influential than additive because SCA (σ^2s) > GCA (σ^2g). The GCA, SCA effects, the x̄ performance of the parents, and hybrids are presented in tables (2, 3, and 4).

4. Discussion

It is depicted from the results that among the female lines L2 (g.c.a.= 0.128, x̄/Mean= 1.85m), L5 (g.c.a.= 0.099, x̄/Mean= 1.59m) and among testers T3 (g.c.a.= 0.046, x̄/Mean= 1.35m) were the better general combiners for the plant height (m). For the trait photosynthesis rate, the female lines L8 (g.c.a.= 3.055, x̄/Mean= 13.37), L10 (g.c.a.= 1.322, x̄/Mean= 4.73) and L4 (g.c.a.= 2.812, x̄/Mean= 2.43) were the better general combiners. In the character transpiration rate, the female lines L6 (g.c.a.= 1.006, x̄/Mean= 7.99), L7 (g.c.a.= 1.068, x̄/Mean= 6.68), L11 (g.c.a.= 1.105, x̄/Mean= 3.28), and among testers T4 (g.c.a.= 0.499, x̄/Mean= 4.43) were the better general combiners. For the character stomatal conductance, the female lines L4 (g.c.a.= 292.84, x̄/Mean= 246.00), L13 (g.c.a.= 80.369, x̄/Mean= 287.00), L8 (g.c.a.= 75.369, x̄/Mean= 294.00), and among testers T1 (g.c.a.= 53.415, x̄/Mean= 597.33) were the better general combiners.

In the character root yield/plot (g) the female lines L4 (g.c.a.= 71.585, x̄/Mean= 553.33), L13 (g.c.a.= 63.918, x̄/Mean= 383.33), and among testers T3 (g.c.a.= 31.149, x̄/Mean= 583.33) followed by T1 (g.c.a.= 26.046, x̄/Mean= 433.33) were the better general combiners; In the essential oil trait the female lines L1 (g.c.a.= 0.240, x̄/Mean= 0.80) followed by L3 (g.c.a.= 0.143, x̄/Mean= 0.81), L2 (g.c.a.= 0.111, x̄/Mean= 0.85), L9 (g.c.a.= 0.203, x̄/Mean= 0.78) were the better general combiners. For the character the essential oil/plot (g) the female lines L10 (g.c.a.= 1.156, x̄/Mean= 0.97), L7 (g.c.a.= 0.869, x̄/Mean= 3.50), L11 (g.c.a. = 0.802, x̄/Mean=5.00), L9 (g.c.a.= 0.669, x̄/Mean= 1.67), and L2 (g.c.a. = 0.556, x̄/Mean=2.57), and among testers T3 (g.c.a.= 0.391, x̄/Mean= 4.67) and T4 (g.c.a.=0.330, x̄/Mean=5.67) were the better general combiners. The female lines for the character Khusimol content (%) L3 (g.c.a.= 8.500, x̄/Mean= 14.24), L6 (g.c.a.= 6.550, x̄/Mean= 9.17), L11 (g.c.a.= 3.764, x̄/Mean= 12.53), and among testers T4 (g.c.a.= 1.878,

$\bar{x}$/Mean= 0.12) and T2 (g.c.a.= 0.957, $\bar{x}$/Mean= 24.20) and T1 (g.c.a.= 0.843, $\bar{x}$/Mean= 23.89) were the better general combiners.

The female lines for the character Khusinol content (%) L12 (g.c.a.= 9.360, $\bar{x}$/Mean= 8.43), L11 (g.c.a.= 8.868, $\bar{x}$/Mean= 50.50), L9 (g.c.a.= 5.993, $\bar{x}$/Mean= 8.67), L1 (g.c.a.= 4.783, $\bar{x}$/Mean= 15.87), L5 (g.c.a.= 3.848, $\bar{x}$/Mean= 50.00), and among testers T5 (g.c.a.= 7.088, $\bar{x}$/Mean= 3.89) and T2 (g.c.a.= 4.792, $\bar{x}$/Mean= 57.31) were the better general combiners. The lines for the character $\propto$-vetivone content (%) L13 (g.c.a.= 1.737, $\bar{x}$/Mean= 3.10), L12 (g.c.a.= 0.494, $\bar{x}$/Mean= 4.18), L6 (g.c.a.= 0.411, $\bar{x}$/Mean= 1.19), L10 (g.c.a.= 0.342, $\bar{x}$/Mean= 1.10), and among testers T2 (g.c.a.= 0.0.360, $\bar{x}$/Mean= 2.32), T5 (g.c.a.= 0.668, $\bar{x}$/Mean= 0.01) and T1 (g.c.a.= 0.629, $\bar{x}$/Mean= 0.02) were the better general combiners and for the character β-vetivine content (%) the female lines L3 (g.c.a.= 1.155, $\bar{x}$/Mean= 3.60), L4 (g.c.a.= 1.022, $\bar{x}$/Mean= 3.10), L5 (g.c.a.= 0.880, $\bar{x}$/Mean= 4.18), L9 (g.c.a.= 0.868, $\bar{x}$/Mean= 1.05), L10 (g.c.a.= 0.535, $\bar{x}$/Mean= 2.65), and among testers T4 (g.c.a.= 0.227, $\bar{x}$/Mean= 1.047), and T5 (g.c.a.= 0.183, $\bar{x}$/Mean= 0.001) were showed the better gca in the traits (Table 2). The parents, Line 7 (g.c.a.= 0.869) and tester T3 (g.c.a.=0.391) are beneficial to make the hybrids in hybridization programme for the high yield of essential oil /plot (ml). The lines L1 (-0.068) and L2 (-0.067) and T2 tester with high (-) g.c.a. effect were responsible for dwarf stature of the plants. The lines L2 and Line L5 and tester T3 having positive GCA effects were better for tall plants.

The lines L10 followed by L7 and L11 was better for the essential oil yield/plot in order. The line 8 was good for GCA effect for photosynthesis rate/net CO2 assimilation rate (u mol m^{-2} s^{-1}) 3.055, stomatal conductance (m mol m^{-2} s^{-1}) 75.369 and for α-vetivone content 0.251. The g.c.a. effect of L10 was high (1.332) for photosynthesis rate and good for transpiration rate (0.850), for the essential oil yield/ plot (ml) (1.156), for α-vetivone content (0.342) and β-vetivone content (0.535), respectively. The line 6 (-0.009) showed (-) g.c.a effect for the plant height and photosynthesis rate (-1.068), stomatal conductance (m mol m^{-2} s^{-1}) (-43.097), essential oil content (-0.091), khusimol content (-4.777), khusinol content (-3.282), α-vetivone content (-0.915) and β-vetivone content (-0.852) but positive GCA effects for the characters transpiration rate (1.068), essential oil yield (0.869), therefore, selection could be made on the basis of desired characters on the basis of g.c.a. and *per se* performance (Table 2). Generally it is, assumed that if hybrid performs well as *per se* also exhibit better s.c.a. the hybrid L7 × T3 with highest SCA effect (5.65) (L7= high gca 0.860; low mean 3.50; tester (T3)= high gca 0.391 medium mean 4.67); the hybrid L10 × T5 with highest SCA effect (3.14), L10= high gca 1.156; low mean 0.97; tester (T5)= low gca -0.056 medium mean 3.23 produced better essential oil yield for example, 10.33 and 7.67 (ml), respectively (Tables 2-6).

On other hand the hybrid L2 × T3 with highest SCA effect (1.96) (L2= high g.c.a. 0.556; low mean 2.57; tester (T3) = high g.c.a., 0.391 medium mean 4.67); the hybrid L4 × T5 with highest SCA effect (3.03) (L4= low g.c.a. -0.066; low mean medium 3.17; tester (T5) = low g.c.a., -0.056 medium mean 3.23) both also produced better essential oil/plot (g) i.e. 6.33 per plot (g). The hybrid L13 × T3 having high SCA effect (0.24) for photosynthesis rate (L13= low gca 0.095; low mean medium 2.43; tester (T3) = low g.c.a., -0.344 high mean 12.87) showed in the rage of medium to high photosynthesis rate (9.17). For the character stomatal conductance, the hybrid L8 × T3 with highest SCA effect (473.48) (L8= high gca 75.369; high mean 294; tester (T3)= low g.c.a., 8.390 high mean 503.67); the hybrid L13 × T1 with highest SCA effect (423.45) (L13= high g.c.a., 80.369; high mean 287.00; tester (T1)= high gca 53.415 high mean 597.33) produced better per se performance i.e. 866.00. The hybrid L13 × T1 with highest SCA effect (423.45) (L13= high g.c.a., 63.918; high mean 383.33; tester (T1)= high g.c.a., 26.046 high mean 433.33); the hybrid L10 × T3 with highest SCA effect (149.72) (L13= low g.c.a, 6.718; high mean 583.33; tester (T3)= high gca 31.149 high mean 583.33) produced better per se performance i.e. 683.33 and 616.67 in order for the character root yield/plot. Notably, the hybrid L1 × T2 with highest SCA effect (1.33) (L1= high g.c.a., 0.240; high mean 0.80; tester (T2)= low g.c.a., -0.045 high mean 1.67); the hybrid L3 × T3 with highest SCA effect (1.30) (L3= high gca 0.209; high mean 1.02; tester (T3)= low gca 0.019 high mean 1.45) produced better per se performance i.e. 2.45 % for the character essential oil content (%) (Table 2-6).

The three hybrids showed high mean performance for the khusimol content (%) namely, L8 × T4 (34.50), L3 × T1 (34.30) and L13 × T4 (34.17) % with high s.c.a. The s.c.a. value expressed that the crosses L7 × T3 followed by L10 × T5, L2 × T3 and L4 × T5 were pre-eminent and could be used in hybridization programme (Table 3; Figure 1 and 2). The lines and testers used in the promising hybrids were high × high (L7 × L3) and high × poor/low (L10 × T5) and poor × poor (L4 × L5 for the oil yield/plot and it's the supporting traits were m × h, m × m and m × poor, respectively. The promising parents involved for the hybrids were low × low (L13 × L3) and high × poor/low (L4 × T1), etc., for the photosynthesis rate.

The allied genetic parameters of the Genetic components in all traits are presented in the table (5). In this crop, the non-additive variance was higher than an additive variance in the present hybrids in all traits. Kandalkar *et al*., (1992) [4], Lal, *et al*., (2014) and Misra, *et al*., (2014) [16] is also reported the non-additive (dominance) variance was greater than additive variance or vice versa in all the traits. The magnitude of SCA was >GCA variance for all traits, expressing the predominance of nonadditive gene action in these traits.

The $^{\wedge}\sigma^2g/^{\wedge}\sigma^2s$ ratio was > 1 than the unity, also depicting the predominance of nonadditive gene action in all the characters, similar results have also reported by several researchers (Lal, 2013; Lal *et al*., 2017a; Lal *et al*., 2017b; Lal *et al*., 2017c; Lal *et al*., 2018a; Lal *et al*., 2018b; Kandalkar *et al*., 1992; Saini, 1992; Panwar *et al*., 2008) [6, 7, 8, 9, 10, 11, 4, 20, 18]. Therefore, heterosis and transgressive breeding could be useful for the improvement of these traits in vetiver. The heterosis and transgressive breeding approach could be the best choice (Lenz *et al*., 1986; Sharma *et al*. 1988 and Lal, 2013) [15, 23, 6]. the narrow sense heritability ($^{\wedge}h^2$ (ns) % was low in all the traits (008-3.796 %) and GA was low in the most characters (0.008-2.93) except the two traits i.e. high namely root yield/plot (ml) 180.44 and stomatal conductance 160.99 %. These results (predominantly for dominance variance) are also in agreement with the several research reports (Sharma, 1996; Sharma and Gupta, 1994; Sharma *et al*. 1988 and Lal, 2013, Veselovskaya, 1996) [21, 22, 23, 6, 25].

The hybrids $L_7\times T_3$ followed by $L_{10}\times T_5$, $L_2\times T3$, and $L_4\times T_5$ were best for the essential oil yield of better quality and The three hybrids showed high mean performance for the khusimol content (%) namely, L8 × T4 (34.50), L3 × T1 (34.30) and L13 × T4 (34.17) % with high s.c.a. Therefore, these crosses could be exploited for large area cultivation.

Table 1: Pooled analysis of variance (ANOVA) for Lines × Testers analysis in the vetiver

Sources of variation	d. f.	Character's Mean Sum of Squares (m.s.s.)										
		Plant height (m.)	**Photosynthesis rate/net Co$_2$ assimilation rate (u mol m^{-2} s^{-1})**	**Transpiration rate (m mol m^{-2} s^{-1})**	**Stomatal conductance (m mol m^{-2} s^{-1})**	**Root yield/plot (g)**	**Essential oil content (%)**	**Essential oil yield/plot (g)**	**Khusimol content (%)**	**Khusinol content (%)**	**α-vetivone content (%)**	**β-vetivone content (%)**
Replications	2	0.05	0.33	0.28	3104.00	4872.00	0.01	0.09	2.38	18.90	0.18	0.04
Treatments	82	0.08**	36.96**	5.65**	86748.05**	23023.17**	0.43**	10.00**	321.49**	1360.83**	11.40**	4.69**
Parents	17	0.12**	43.60**	6.97**	96160.85**	16418.00**	0.24**	13.78**	283.56**	1511.49**	10.74**	6.40**
Hybrids (H)	64	0.07**	35.48**	5.33**	82748.00**	23933.88**	0.49**	9.12**	329.01**	1211.01**	11.05**	4.09**
Parents × Hybrids	1	0.02	10.81	3.89	182742.00**	77024.00**	0.04	2.03*	484.86**	8388.21**	45.14**	13.64**
Lines (L)	12	0.06**	36.90*	7.68**	160155.70**	42847.67**	0.54**	10.93**	354.33**	553.11**	8.36**	10.79**
Testers (T)	4	0.04**	20.93	6.28**	41832.50**	37016.00**	0.09	6.23***	803.48**	1426.88**	23.70**	1.57**
Lines × Testers	48	0.07**	36.34**	4.66**	66805.88**	18115.25**	0.51**	8.91**	283.15**	1357.50**	10.66**	2.63**
Error	164	0.01	15.77	1.07	5952.48	5473.54	0.08	0.54	0.43	6.24	0.15	0.01
Total	248											

Where d. f. =degree of freedom*-$p<0.05$; **-$p<0.01$

Table 2: General combining ability (g.c.a) effects and mean of 13 lines and 5 testers for eleven economic traits in vetiver.

Lines and testers	**Plant height (m.)**	**Photosynthesis rate/net Co$_2$ assimilation rate (u mol m^{-2} s^{-1})**	**Transpiration rate (m mol m^{-2} s^{-1})**	**Stomatal conductance (m mol m^{-2} s^{-1})**	**Root yield/plot (g)**	**Essential oil content (%)**	**Essential oil yield/plot (g)**	**Khusimol content (%)**	**Khusinol content (%)**	**α-vetivone content (%)**	**β-vetivone content (%)**
L1. **Lines**	-0.068*	-0.894	-0.388	-70.764**	26.918	0.240**	-0.126	-4.683**	4.783**	-0.036	-0.403**
$\bar{x}$	1.75	3.83	3.60	276.33	546.67	0.80	3.48	31.57	15.87	3.22	0.023
L2.	0.128**	-0.665	-0.454	-27.497	30.251	0.111**	0.556**	-8.723**	-9.424**	-0.966**	-1.449**
$\bar{x}$	1.85	8.23	6.31	313.67	400.00	0.85	2.57	33.23	8.57	4.67	2.467
L3.	-0.017	-0.555	-0.527	-72.631**	-39.815*	0.209**	-0.118	8.500**	-4.933**	0.189	1.155**
$\bar{x}$	1.35	13.40	8.47	256.00	465.00	1.02	3.50	14.24	15.40	7.34	3.600
L4.	0.014	2.812*	-0.244	292.836**	71.585**	0.143**	-0.066	1.455**	-0.452	-0.311**	1.022**
$\bar{x}$	1.35	2.43	5.32	246.00	553.33	0.81	3.17	13.12	50.33	1.06	3.190
L5.	0.099**	-0.678	-0.386	37.303	7.585	-0.310**	-0.011	0.874**	3.848**	-1.070**	0.880**
$\bar{x}$	1.59	6.80	5.28	283.33	483.33	1.08	7.67	8.33	50.00	1.16	4.183
L6.	0.039	-0.205	1.006**	-58.497**	32.251	-0.227**	-0.391*	6.550**	-3.617**	0.411**	-0.108**
$\bar{x}$	1.83	11.50	7.99	261.33	450.00	1.31	1.83	9.17	51.73	1.19	3.497
L7.	-0.009	-2.298*	1.068**	-43.097*	30.251	-0.091	0.869**	-4.777**	-3.282**	-0.915**	-0.852**
$\bar{x}$	1.54	12.87	6.68	204.00	533.33	0.85	3.50	15.20	52.00	4.38	1.180
L8.	-0.061*	3.055**	-0.738*	75.369**	12.918	-0.272**	-1.724**	-4.863**	-0.645	0.251*	-1.029**
$\bar{x}$	1.44	13.37	5.33	294.00	416.67	0.73	3.67	7.90	5.50	2.16	1.170
L9.	0.003	-0.665	-0.272	-50.431*	-81.082**	0.203*	0.669**	1.510**	5.993**	-0.150	0.868**
$\bar{x}$	1.53	7.63	3.74	213.00	513.33	0.78	1.67	8.70	8.67	2.75	1.050
L10.	-0.067*	1.332*	0.850**	-62.831**	6.718	-0.061	1.156**	-1.263**	-7.475**	0.342**	0.535**
$\bar{x}$	1.35	4.73	3.37	222.00	583.33	0.87	0.97	10.53	54.37	1.10	2.647
L11.	-0.049	-1.624*	1.105**	-27.497	-79.349**	0.063	0.802**	3.764**	8.868**	0.023	0.040
$\bar{x}$	1.84	6.70	3.28	662.67	348.33	0.87	5.00	12.53	50.50	1.06	3.493
L12.	-0.022	0.289	-0.692*	-72.631**	-82.149**	0.092	0.249	-0.050	9.360**	0.494**	-0.616**
$\bar{x}$	1.59	8.83	4.36	590.00	468.33	0.82	0.93	13.63	8.43	4.18	1.197
L13.	0.011	0.095	-0.328	80.369**	63.918**	-0.101	-0.800**	1.704**	-3.023**	1.737**	-0.036
$\bar{x}$	1.35	2.43	4.39	287.00	383.33	0.92	0.90	0.05	46.83	3.10	4.167
T1. Testers	0.011	-0.048	-0.224	53.415**	26.046*	-0.059	-0.610**	0.843**	-3.127**	0.629**	-0.048*
$\bar{x}$	1.75	6.80	4.06	597.33	433.33	1.17	3.50	23.89	5.60	0.02	0.023
T2	-0.038*	-0.706	0.039	-12.764	3.585	-0.045	-0.056	0.957**	4.792**	0.360**	-0.177**
$\bar{x}$	1.83	11.50	4.68	788.00	513.33	1.67	8.67	24.20	57.31	2.32	3.493
T3	0.046**	-0.344	0.226	8.390	31.149*	0.019	0.391**	-7.776**	-7.916**	-0.623**	-0.196**
$\bar{x}$	1.35	12.87	4.81	505.67	583.33	1.45	4.67	21.42	55.31	1.19	2.627
T4	0.005	-0.131	0.499**	-25.328*	-42.380**	0.046	0.330*	1.878**	-0.837*	-1.035**	0.227**
$\bar{x}$	1.35	13.37	4.43	470.33	348.33	0.60	5.67	0.12	54.41	1.06	1.047
T5	-0.024	1.229	-0.540**	-23.713	-18.380	0.038	-0.056	4.098	7.088**	0.668**	0.193**
$\bar{x}$	1.59	9.37	3.45	270.33	468.33	0.65	3.23	1.67	3.69	0.010	0.001
S.E. (g.c.a. Lines)	0.026	1.025	0.267	19.921	19.102	0.071	0.189	0.169	0.645	0.099	0.027
S.E. (g.c.a. Testers)	0.016	0.636	0.165	12.354	11.847	0.044	0.117	0.105	0.400	0.061	0.017
S.E. D (g.c.a Lines)	0.037	1.450	0.377	28.172	27.015	0.100	0.267	0.238	0.912	0.140	0.039
S.E.D (g.c.a Testers)	0.023	0.899	0.234	17.472	16.754	0.062	0.166	0.148	0.566	0.087	0.024

*$P < 0.05$, **$P < 0.01$; $\bar{x}$ = Mean; S.E. = standard error; S.E.D.= standard error difference

Table 3: Specific combining ability effects of sixty five crosses for eleven economic traits in vetiver.

S. No.	Crosses	Plant height (m.)	Photosynthesis rate/net Co$_2$ assimilation rate N (u mol m^{-2} s^{-1})	Transpiration rate (m mol m^{-2} s^{-1})	Stomatal conductance (m mol m^{-2} s^{-1})	Root yield/plot (g)	Essential oil content (%)	Essential oil yield/plot (g)	Khusimol content (%)	Khusinol content (%)	α- vetivone content (%)	β-vetivone content (%)
1.	L1×T1	0.10	-2.61	0.20	-34.75	-82.05	-0.34	-0.59	-2.70**	-15.47**	-1.77**	0.09
2.	L1×T2	-0.07	-1.06	-0.30	33.76	87.08	1.33**	0.09	-4.95**	-28.44**	-2.50**	1.30**
3.	L1×T3	0.23**	3.34	-0.12	30.28	29.52	-0.29	0.98	0.85	-15.71**	1.93**	0.51**
4.	L1×T4	-0.06	-0.31	-0.72	-17.67	-30.28	-0.33	2.04**	-6.70**	34.41**	-1.11**	-0.5**
5.	L1×T5	-0.19*	0.63	0.94	-11.62	-4.28	-0.37	-2.52**	13.51**	25.21**	3.45**	-1.42**
6.	L2×T1	0.16*	-1.75	0.64	-22.02	-68.71	0.24	-2.80**	1.20*	3.44	1.71**	0.26**
7.	L2×T2	-0.04	-2.99	-1.19	45.50	-29.58	-0.38	1.08	-0.71	-5.61**	-1.68**	0.06
8.	L2×T3	-0.37**	-3.36	0.21	-62.66	56.18	-0.16	1.96**	4.52**	9.77**	-0.59	-0.04
9.	L2×T4	0.07	0.83	0.74	-0.94	99.72	0.70**	-0.64	-8.46**	6.48**	1.91**	0.17
10.	L2×T5	0.18*	7.27*	-0.40	40.11	-57.61	-0.40	0.41	3.45**	-14.08**	-1.35**	-0.44**
11.	L3×T1	-0.19*	3.04	0.96	-46.22	-23.65	-0.41	0.54	7.68**	-4.99*	0.18	-0.31**
12.	L3×T2	-0.14	3.75	0.25	-39.04	-26.18	-0.31	2.05**	-10.90**	37.48**	1.09**	-0.22*
13.	L3×T3	0.01	-2.47	-0.92	103.48	19.25	1.30**	0.54	-4.75**	-3.41	-1.03**	-0.10
14.	L3×T4	0.30**	-3.68	0.25	-64.14	-15.21	-0.28	-1.80**	6.01**	-10.48**	0.65*	0.18*
15.	L3×T5	0.02	-0.64	-0.54	45.91	45.79	-0.29	-1.32*	1.96**	-18.60**	-0.88**	0.45**
16.	L4×T1	0.07	5.07	0.48	210.98**	-15.05	-0.17	1.42*	-3.91**	-0.03	0.98**	-0.16
17.	L4×T2	-0.27**	0.33	0.99	-136.17*	9.08	0.19	-2.58**	-4.99**	-14.75**	3.59**	0.56**
18.	L4×T3	-0.13	-1.57	-1.38	-406.32**	51.52	-0.47*	-3.18**	2.57**	-0.44	1.10**	-0.16
19.	L4×T4	0.02	-1.51	-0.57	215.73**	-109.94*	-0.22	1.31*	-2.08**	-9.99**	-0.94**	0.45**
20.	L4×T5	0.31**	-2.32	0.50	115.78	64.39	0.67**	3.03**	8.40**	24.82**	-2.53**	-0.69**
21.	L5×T1	-0.04	-1.94	0.01	128.52*	53.95	0.12	0.86	-17.41**	22.17**	1.63**	-0.04
22.	L5×T2	-0.04	3.49	0.36	111.70	-56.92	0.01	0.98	12.43**	25.65**	1.82**	0.61**
23.	L5×T3	0.20*	-0.31	0.29	-144.46*	-34.48	-0.03	-1.64**	3.23**	-10.21**	0.61	-0.89**
24.	L5×T4	-0.02	1.78	-0.36	-50.41	22.39	-0.05	0.49	-9.53**	-16.29**	0.43	-0.28**
25.	L5×T5	-0.09	-3.02	-0.30	-45.35	15.06	-0.05	-0.69	11.29**	-21.31**	-1.24**	0.59**
26.	L6×T1	-0.13	-4.11	-0.56	-108.68	59.29	-0.02	0.24	9.06**	-1.03	2.60**	-1.37**
27.	L6×T2	0.22**	-3.45	-2.65**	-34.84	51.75	-0.05	0.36	8.58**	36.15**	0.35	-1.37**
28.	L6×T3	0.14	0.58	-1.24	54.01	-109.15*	-0.12	-0.76	-3.52**	-7.23**	-1.69**	0.78**
29.	L6×T4	-0.15	8.17*	3.46**	89.06	-27.28	-0.11	0.47	-16.87**	-14.40**	-0.19	0.62**
30.	L6×T5	-0.08	-1.19	0.99	0.45	25.39	0.31	-0.31	2.74**	-13.18**	-1.06**	1.36**
31.	L7×T1	0.08	-1.12	-1.73*	-64.08	-22.05	0.46*	-1.18*	-2.78**	-0.87	0.27	2.33**
32.	L7×T2	0.03	1.51	2.65**	44.76	103.75*	0.01	-2.40**	-5.79**	-18.02**	-1.51**	-0.23*
33.	L7×T3	-0.12	3.28	0.89	-30.72	-57.15	-0.03	5.65**	0.28	-1.85	-0.63*	-0.65**
34.	L7×T4	0.08	-3.34	0.14	-56.01	-0.28	-0.15	-0.96	15.96**	40.72**	2.66**	-0.93**
35.	L7×T5	-0.08	-0.33	-1.95*	106.05	-24.28	-0.29	-1.10	-7.66**	-19.98**	-0.80*	-0.53**
36.	L8×T1	-0.03	0.29	0.11	-290.88**	-84.71	-0.10	2.58**	-7.96**	-0.31	-1.57**	-0.53**
37.	L8×T2	0.18*	2.32	-0.67	-113.04	41.08	-0.04	0.36	2.10**	-15.06**	0.33	-0.32**
38.	L8×T3	-0.09	2.46	-0.16	473.48**	16.85	0.14	-0.72	-3.17**	39.78**	-0.84**	-0.35**
39.	L8×T4	0.04	-1.76	-0.05	93.86	67.06	-0.07	-0.83	20.21**	-15.16**	-3.12**	-0.44**
40.	L8×T5	-0.09	-3.32	0.78	-163.42*	-40.28	0.06	-1.38*	-11.18**	-9.25**	2.12**	1.63**
41.	L9×T1	-0.03	-1.75	0.30	-112.08	92.62	-0.32	-0.15	13.64**	-14.48**	-0.58	0.63**
42.	L9×T2	0.12	-2.99	0.21	30.76	15.08	-0.30	0.46	-4.91**	21.70**	-1.26**	0.62**
43.	L9×T3	-0.16*	-3.36	0.01	46.94	-92.48	0.19	-0.15	-0.84	-11.86**	0.84**	-0.23*
44.	L9×T4	-0.02	0.83	-1.12	22.99	14.39	0.74**	0.21	-15.16**	-15.27**	-0.99**	-0.45**
45.	L9×T5	0.10	7.27*	0.59	11.38	-29.61	-0.30	-0.37	7.28**	19.90**	1.98**	-0.57**
46.	L10×T1	0.04	1.15	-1.64	-16.02	-141.85*	-0.01	0.10	-1.62**	3.21	3.08**	0.88**
47.	L10×T2	0.03	1.86	-1.42	38.83	-14.38	0.05	-0.19	1.10*	-10.23**	-1.15**	-0.60**
48.	L10×T3	0.01	-2.25	2.22**	22.34	149.72*	-0.02	-1.13	-7.07**	5.45**	1.53**	-0.19*
49.	L10×T4	-0.14	-0.03	1.29	-25.61	-80.08	-0.21	-1.91**	15.21**	2.37	-1.49**	0.05
50.	L10×T5	0.07	-0.73	-0.44	-19.55	86.59	0.20	3.14**	-7.61**	-0.79	-1.98**	-0.14
51.	L11×T1	0.12	-1.79	1.30	-22.02	7.55	0.15	-0.38	8.45**	-11.19**	-0.28	-1.20**
52.	L11×T2	-0.02	0.83	1.64	45.50	-4.98	-0.11	1.00	12.60**	17.93**	2.65**	1.73**
53.	L11×T3	-0.01	3.77	0.51	-62.66	-117.55*	-0.11	-0.45	-4.50**	-1.80	-0.33	-0.13
54.	L11×T4	-0.14	-1.71	-1.98*	-0.94	-102.99	0.03	-0.16	-5.25**	-24.71**	-0.10	-0.86**
55.	L11×T5	0.05	-1.10	-1.47	40.11	11.99	0.04	-0.05	-11.30**	19.77**	-1.93**	0.46**
56.	L12×T1	-0.01	0.39	-0.41	-46.22	60.35	-0.17	-0.06	-2.24**	26.99**	-0.42	0.59**
57.	L12×T2	-0.02	-5.35	-0.38	-39.04	-105.85	-0.11	-0.78	1.32*	-29.07**	-2.52**	-0.73**
58.	L12×T3	0.06	-1.34	0.16	103.48	90.25	-0.16	-0.56	9.12**	-4.06*	2.09**	0.34**
59.	L12×T4	0.01	3.14	-0.20	-64.14	40.46	0.17	0.73	-6.64**	-14.47**	-1.74**	1.08**
60.	L12×T5	-0.03	3.15	0.83	45.91	-85.21	0.28	0.68	-1.56**	20.61**	2.59**	-1.29**
61.	L13×T1	-0.13	5.12	0.38	423.45**	164.29**	0.58**	-0.56	-1.42**	-7.43**	-2.56**	-1.16**
62.	L13×T2	0.04	1.78	0.51	11.30	-69.92	-0.28	-0.40	-5.87**	-17.71**	0.80*	-1.43**
63.	L13×T3	0.24**	1.22	-0.47	-127.19*	-2.48	-0.23	-0.52	3.30**	1.16	0.80*	1.14**
64.	L13×T4	0.03	-2.43	-0.88	-141.81*	-83.94	-0.21	1.05	13.31**	36.78**	0.93**	0.88**
65.	L13×T5	-0.18*	-5.69	0.47	-165.75**	-7.94	0.14	0.43	-9.31**	-12.79**	1.63**	0.58**
	S.E. (sca)	0.06	2.29	0.60	44.54	42.71	0.16	0.42	0.38	1.44	0.22	0.06
	S.E.D. (sca)	0.08	3.24	0.84	62.99	60.41	0.22	0.60	0.53	2.04	0.31	0.09

*$p<0.05$; **-$p<0.01$; S.E. = standard error; S.E.D. = standard error difference

Table 4: Mean (x̄) performance of sixty five hybrids of eleven economic traits in vetiver.

S. No.	Hybrids	Plant height (m.)	Photosynthesis rate/net Co_2 assimilation rate (u mol m^{-2} s^{-1})	Transpiration rate (m mol m^{-2} s^{-1})	Stomatal conductance (m mol m^{-2} s^{-1})	Root yield/plot (g)	Essential oil content (%)	Essential oil yield/plot (g)	Khusimol content (%)	Khusinol content (%)	α-vetivone content (%)	β-vetivone content (%)
1.	L1×T1	1.57	4.65	4.26	256.67	400.00	0.76	2.10	10.73	5.13	2.18	2.37
2.	L1×T2	1.37	5.53	4.02	259.00	546.67	2.45	3.33	8.60	8.33	1.19	3.46
3.	L1×T3	1.75	10.30	4.39	276.67	516.67	0.90	4.67	5.67	0.11	4.63	2.65
4.	L1×T4	1.42	6.87	4.06	195.00	383.33	0.88	5.67	7.77	57.3	1.19	2.08
5.	L1×T5	1.27	9.17	4.68	202.67	433.33	0.84	0.73	30.20	56.02	7.45	1.11
6.	L2×T1	1.84	5.73	4.63	312.67	416.67	1.22	0.57	10.60	9.83	4.73	1.50
7.	L2×T2	1.59	3.83	3.07	314.00	433.33	0.62	5.00	8.80	8.70	1.08	1.17
8.	L2×T3	1.35	3.83	4.66	227.00	546.67	0.89	6.33	5.30	11.37	1.19	1.05
9.	L2×T4	1.75	8.23	5.46	255.00	516.67	1.78	3.67	1.97	15.17	3.27	1.68
10.	L2×T5	1.83	16.03	3.28	297.67	383.33	0.68	4.33	16.10	2.53	1.72	1.04
11.	L3×T1	1.35	10.63	4.88	243.33	391.67	0.67	2.17	34.30	5.90	4.37	3.53
12.	L3×T2	1.35	10.68	4.43	184.33	366.67	0.78	4.23	15.83	56.28	5.00	3.50
13.	L3×T3	1.59	4.83	3.45	348.00	439.67	2.45	3.17	13.25	2.68	1.90	3.60
14.	L3×T4	1.83	3.83	4.90	146.67	331.67	0.90	0.77	33.67	2.70	3.17	4.30
15.	L3×T5	1.52	8.23	3.07	258.33	416.67	0.88	0.87	31.83	2.50	3.34	4.53
16.	L4×T1	1.64	16.03	4.66	866.00	511.67	0.84	4.17	15.66	15.33	4.67	3.55
17.	L4×T2	1.25	10.63	5.46	452.67	513.33	1.22	0.73	14.70	8.53	7.00	4.14
18.	L4×T3	1.48	9.10	3.28	203.67	583.33	0.62	0.57	13.53	10.53	1.33	3.40
19.	L4×T4	1.58	9.37	4.36	792.00	348.33	0.90	5.00	18.53	7.67	1.08	4.44
20.	L4×T5	1.85	9.92	4.39	693.67	546.67	1.78	6.33	31.23	50.40	1.19	3.27
21.	L5×T1	1.62	5.53	4.06	528.00	516.67	0.68	3.67	1.58	41.83	1.29	3.53
22.	L5×T2	1.56	10.30	4.68	445.00	383.33	0.58	4.33	31.53	53.23	4.48	4.05
23.	L5×T3	1.89	6.87	4.81	210.00	433.33	0.60	2.17	13.60	4.67	2.28	2.53
24.	L5×T4	1.63	9.17	4.43	270.33	416.67	0.62	4.23	10.50	5.67	1.69	3.57
25.	L5×T5	1.53	5.73	3.45	277.00	433.33	0.60	2.67	33.53	8.57	1.73	4.40
26.	L6×T1	1.47	3.83	4.90	195.00	546.67	0.62	2.67	33.73	11.17	7.00	1.21
27.	L6×T2	1.77	3.83	3.07	202.67	516.67	0.60	3.33	33.37	56.27	4.48	1.09
28.	L6×T3	1.77	8.23	4.66	312.67	383.33	0.60	2.67	12.53	0.18	1.46	3.19
29.	L6×T4	1.46	16.03	9.63	314.00	391.67	0.63	3.83	8.83	0.09	2.55	3.48
30.	L6×T5	1.48	8.03	6.13	227.00	468.33	1.05	2.67	30.67	8.93	3.38	4.18
31.	L7×T1	1.63	4.73	3.78	255.00	463.33	1.23	2.50	10.57	11.67	3.35	4.17
32.	L7×T2	1.53	6.70	8.43	297.67	566.67	0.80	1.83	7.67	2.43	1.30	1.48
33.	L7×T3	1.47	8.83	6.85	243.33	433.33	0.82	10.33	5.00	5.90	1.20	1.04
34.	L7×T4	1.63	2.43	6.38	184.33	416.67	0.73	3.67	30.33	55.55	4.08	1.18
35.	L7×T5	1.44	6.80	3.25	348.00	416.67	0.59	3.13	8.93	2.77	2.32	1.55
36.	L8×T1	1.47	11.50	3.82	146.67	383.33	0.50	3.67	5.30	14.87	2.67	1.13
37.	L8×T2	1.63	12.87	3.30	258.33	486.67	0.57	2.00	15.47	8.03	4.30	1.22
38.	L8×T3	1.44	13.37	3.99	866.00	490.00	0.82	1.37	1.47	50.17	2.16	1.17
39.	L8×T4	1.53	9.37	4.39	452.67	466.67	0.63	1.20	34.50	2.30	2.55	1.50
40.	L8×T5	1.37	9.17	4.17	197.00	383.33	0.75	0.27	5.53	16.13	6.40	3.53
41.	L9×T1	1.53	5.73	4.48	199.67	466.67	0.75	3.33	33.27	7.33	3.27	4.19
42.	L9×T2	1.63	3.83	4.65	276.33	366.67	0.78	4.50	14.83	51.43	2.32	4.05
43.	L9×T3	1.44	3.83	4.64	313.67	286.67	1.33	4.33	10.17	5.17	3.43	3.18
44.	L9×T4	1.53	8.23	3.78	256.00	320.00	1.91	4.63	5.50	8.83	1.19	3.38
45.	L9×T5	1.63	16.03	4.45	246.00	300.00	0.87	3.67	30.17	51.92	5.87	3.23
46.	L10×T1	1.53	10.63	3.66	283.33	320.00	0.80	4.07	15.23	11.55	7.42	4.10
47.	L10×T2	1.47	10.68	4.14	272.00	425.00	0.87	4.33	18.07	6.03	2.92	2.50
48.	L10×T3	1.53	6.93	7.97	276.67	616.67	0.87	3.83	1.17	9.00	4.62	2.88
49.	L10×T4	1.34	9.37	7.31	195.00	313.33	0.69	3.00	33.10	13.00	1.18	3.55
50.	L10×T5	1.53	10.03	4.54	202.67	504.00	1.10	7.67	12.50	17.77	2.40	3.33
51.	L11×T1	1.63	4.73	6.85	312.67	383.33	1.08	3.23	30.33	13.50	3.73	1.53
52.	L11×T2	1.44	6.70	7.46	314.00	348.33	0.83	5.17	34.60	50.53	6.40	4.33
53.	L11×T3	1.53	10.00	6.51	227.00	263.33	0.90	4.17	8.77	18.10	2.43	2.45
54.	L11×T4	1.37	4.73	4.30	255.00	410.33	1.07	4.40	17.67	2.27	2.25	2.14
55.	L11×T5	1.53	6.70	3.77	297.67	343.33	1.07	4.17	13.83	54.67	2.12	3.43
56.	L12×T1	1.53	8.83	3.34	243.33	433.33	0.79	3.00	15.83	52.17	4.07	2.67
57.	L12×T2	1.47	2.43	3.64	184.33	244.67	0.86	2.83	19.50	4.03	1.70	1.21
58.	L12×T3	1.63	6.80	4.37	348.00	468.33	0.88	3.50	18.57	16.33	5.33	2.27
59.	L12×T4	1.53	11.50	4.28	146.67	345.00	1.23	4.73	12.47	13.00	1.08	3.43
60.	L12×T5	1.47	12.87	4.27	258.33	243.33	1.33	4.30	19.77	56.00	7.12	1.03
61.	L13×T1	1.44	13.37	4.50	866.00	683.33	1.35	1.46	18.40	5.36	3.17	1.48
62.	L13×T2	1.56	9.37	4.89	387.67	426.67	0.50	2.17	14.07	3.00	6.26	1.09
63.	L13×T3	1.84	9.17	4.10	270.33	521.67	0.62	2.50	14.50	9.17	3.68	3.63
64.	L13×T4	1.59	5.73	3.95	222.00	366.67	0.66	4.00	34.17	51.87	5.00	3.80
65.	L13×T5	1.35	3.83	4.27	199.67	466.67	1.00	3.00	13.77	10.22	7.40	3.46
S.E. (g.c.a. Lines)		0.026	1.025	4.10	19.921	19.102	0.071	0.189	0.169	0.645	0.099	0.027
S.E. (g.c.a. Testers)		0.016	0.636	3.96	12.354	11.847	0.044	0.117	0.105	0.400	0.061	0.017
S.E. D. (g.c.a. Lines)		0.037	1.450	4.27	28.172	27.015	0.100	0.267	0.238	0.912	0.140	0.039
S.E.D. (g.c.a Testers)		0.023	0.899	0.234	17.472	16.754	0.062	0.166	0.148	0.566	0.087	0.024

x̄ = Mean; S.E. = standard error; S.E.D. = standard error difference

Table 5: Genetic components and allied genetic parameters for the eleven economic traits in vetiver

Genetic components and allied genetic parameters	Plant height (m.)	Photosynthesis rate/net CO_2 assimilation rate (u mol m^{-2} s^{-1})	Transpiration rate (m mol m^{-2} s^{-1})	Stomatal conductance (m mol m^{-2} s^{-1})	Root yield/plot (g)	Essential oil content (%)	Essential oil yield/plot (g)	Khusimol content (%)	Khusinol content (%)	α-vetivone content (%)	β-vetivone content (%)
$^\wedge\sigma^2$A (for F=0)	-0.0002	-0.041	0.032	759.15	277.08	-0.0010	0.010	2.18	-0.698	0.018	0.070
$^\wedge\sigma^2$A (for F=1)	-0.0001	-0.020	0.016	379.57	138.54	-0.0005	0.005	1.09	-3.488	0.009	0.035
$^\wedge\sigma^2_g$	-0.0001	-0.010	0.008	189.79	69.27	-0.0003	0.003	0.55	-1.744	0.005	0.017
$^\wedge\sigma^2_s$	0.0199	6.855	1.198	20284.47	4213.91	0.1455	2.792	94.24	450.420	3.506	0.872
$^\wedge\sigma^2_g/^\wedge\sigma^2_s$	-0.005	-0.002	0.007	0.010	0.016	-0.002	0.001	0.01	-0.004	0.001	0.019
$(^\wedge\sigma^2_s/^\wedge\sigma_g^2)^{0.5}$	14.11	6.855	12.237	10.34	7.80	22.0227	30.507	13.09	21.182	26.48	7.162
$^\wedge\sigma^2$ D(for F=0)	0.0799	27.420	4.79	81137.87	16855.62	0.5821	11.169	376.96	1801.681	14.023	3.490
$^\wedge\sigma^2$ D(for F=1)	0.0199	6.855	1.198	20284.47	4213.91	0.1455	2.792	94.24	450.420	3.506	0.872
Heritability ($^\wedge h^2$)%	0.360	0.09	0.697	1.43	1.41	0.2292	0.151	1.14	0.008	0.248	3.796
Genetic advance (GA)	0.008	2.93	1.54	180.44	160.99	0.0354	0.167	2.28	1.71	0.077	0.224
Proportional contribution of :											
Lines (L)	15.781	19.503	27.034	36.29	33.57	20.5961	22.459	20.19	8.564	14.183	49.440
Testers (T)	4.034	3.687	7.365	3.16	9.67	1.1616	4.271	15.26	7.364	13.410	2.397
L×T (interaction)	80.185	76.811	65.601	60.55	56.77	78.2423	73.269	64.54	84.072	72.407	48.164
Cov. H.S. (Lines)	-0.001	0.038	0.201	6223.32	1648.83	0.0018	0.134	4.75	53.626	-0.154	0.544
Cov. H.S. (Testers)	-0.0004	0.015	0.077	2393.59	634.16	0.0007	0.052	1.83	20.626	-0.059	0.209
Cov. H.S. (Average)	-0.0001	-0.010	0.008	189.79	69.27	-0.0003	0.003	0.55	1.744	0.004	0.017
Cov. F.S.	0.0155	5.247	1.681	27122.48	8784.96	0.1028	2.709	157.78	375.728	4.649	1.592

σ^2A= variance due to additive; $^\wedge\sigma^2$g=variance due to general combining ability; $^\wedge\sigma^2$s= variance due to specific combining ability; $^\wedge\sigma^2$ D= variance due to dominance; Cov. H.S. = covariance half sib; Cov. F.S. = covariance full sib.

Table 6: Combining ability pattern among the best selected hybrids for the eleven characters in the vetiver

Characters	Hybrids	g.c.a. of parents	s.c.a.	Mean $(\bar{x})$	$^\wedge\sigma^2_g/^\wedge\sigma^2_s$	Genetics /genes (control)	Heritability ($^\wedge h^2$)%	Genetic advance (GA)
Plant height (m.)	L4 × T5	Low × Low	High	High	$^\wedge\sigma^2_g<^\wedge\sigma^2_s$	Non-additive	Low	Low
Photosynthesis rate (u mol m^{-2} s^{-1})	L13 × T3	Low × Low	High	High	$^\wedge\sigma^2_g<^\wedge\sigma^2_s$	Non-additive	Low	Low
Transpiration rate (m mol m^{-2} s^{-1})	L6 × T4	High ×medium	High	High	$^\wedge\sigma^2_g<^\wedge\sigma^2_s$	Non-additive	Low	Low
Stomatal conductance (m mol m^{-2} s^{-1})	L8 × T3	High × Low	High	High	$^\wedge\sigma^2_g<^\wedge\sigma^2_s$	Non-additive	Low	High
Root yield/plot (g)	L10 × T3	Low × high	High	High	$^\wedge\sigma^2_g<^\wedge\sigma^2_s$	Non-additive	Low	High
Essential oil content (%)	L1× T2	High × Low	High	High	$^\wedge\sigma^2_g<^\wedge\sigma^2_s$	Non-additive	Low	Low
Essential oil yield/plot (g)	L2 × T3	High × high	High	High	$^\wedge\sigma^2_g<^\wedge\sigma^2_s$	Non-additive	Low	Low
Khusimol content (%)	L8 × T4	Low × low	High	High	$^\wedge\sigma^2_g<^\wedge\sigma^2_s$	Non-additive	Low	Low
Khusinol content (%)	L7 × T4	Low × low	High	High	$^\wedge\sigma^2_g<^\wedge\sigma^2_s$	Non-additive	Low	Low
α-vetivone content (%)	L4 × T2	Low × high	High	High	$^\wedge\sigma^2_g<^\wedge\sigma^2_s$	Non-additive	Low	Low
β-vetivone content (%)	L7 × T1	Low × Low	High	High	$^\wedge\sigma^2_g<^\wedge\sigma^2_s$	Non-additive	Low	Low

Fig 1: Best hybrid L7× T3, Female L7 and Male T3 for the high essential yield of the vetiver

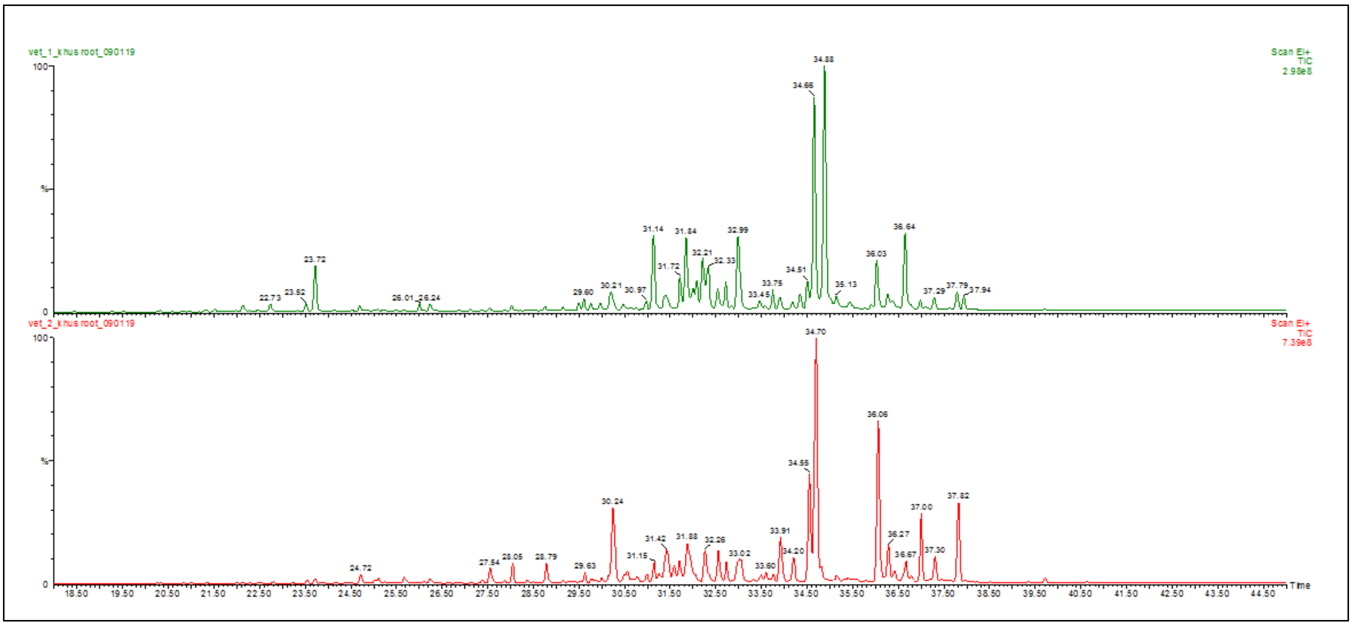

Fig 2: GC chromatogram of the selected hybrids Vet 1 (L7×T3) and Vet. 2 (L10 × T5) of vetiver

5. Conclusions

The females and females × male mean square were found significant for all the characters while, for the male/testers also significant for all the traits except photosynthesis rate and essential oil content. The hybrids $L_7\times T_3$ followed by $L_{10}\times T_5$, $L_2\times T3$, and $L_4\times T_5$ were best for the essential oil yield of better quality and The three hybrids showed high mean performance for the khusimol content (%) namely, L8 × T4 (34.50), L3 × T1 (34.30) and L13 × T4 (34.17) % with high s.c.a.. These crosses could be exploited for large area cultivation. The SCA was >GCA variance for all traits in the present investigation, indicating the predominance of non-additive gene action in the inheritance of these characters. The recurrent crosses followed by rigorous selection will be useful for the improvement in this crop to exploit additive/non-additive gene effects. The diallel and bi-parental mating designs, which concentrates the desirable genes in the heterozygous state generating maximum variability by the breaking linkage blocks followed by further selection, could be used in vetiver crop.

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Conflict of interest

The authors declare that there is no conflict of interest.

Credit authors statements

RKL was involved in planning, actual experimentation, statistical analyses, manuscript preparation; PG, AM, in data collection; RM in distillation, chemical analysis; CS, RM in chemical analysis GC, GC-MS, identification of compound.

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