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EVALUATION OF GENOTYPE × ENVIRONMENT INTERACTION FOR ESSENTIAL OIL YIELD AND ITS RELATED TRAITS FOR IDENTIFICATION OF SUITABLE CULTIVARS IN CITRONELLA (*CYMBOPOGON WINTERIANUS* JOWITT.) IN MEGHALAYA, INDIA

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ABSTRACT
Cymbopogon winterianus Jowitt. is an important aromatic crop, which provides essential oil upon distillation, however this crop is extensively influenced by various environmental factors. Therefore, the present investigation was undertaken to evaluate the stability of Citronella genotypes over four seasons. The outcome of AMMI ANOVA, studied using principal component analysis (PC1), represented 69.79 % for plant height, 76.31 % for number of leaves per clump, 73.61 % for fresh biomass yield per plot and 61.74 % for essential oil yield of GEI sum of squares percentage. High oil yielding and widely stable genotypes were identified almost similar by Eberhart and Russell (1966) and AMMI model analysis. Four genotypes were constituted to be high yielding and stable for fresh biomass yield. Bio-13 (10.27 ml/kg) and Mandakini (9.92 ml/kg) genotypes were registered as high oil yielding and stable. Whereas, JC-4 (9.90 ml/kg) showed better adaptable genotype for essential oil yield. The results revealed consistent performance of these genotypes across the seasons due to their ability to tolerate wide environmental conditions of different seasons. These genotypes can be feasibly utilized in future breeding programmes in Citronella on the basis of high oil yield and stable nature.

INTRODUCTION

Cymbopogon winterianus Jowitt. is one of the vegetatively propagating aromatic and industrially important crop belonging to Poaceae family. It is grown broadly in several parts of tropical and subtropical areas (Shasany *et al.*, 2000). In India, it is mostly cultivated in Karnataka, Uttar Pradesh, Tamil Nadu, Madhya Pradesh and the North Eastern states (Lal *et al.*, 2016). The Citronella essential oil is produced commercially from *C. winterianus* Jowitt. and *C. nardus* Rendle known as Java Citronella and Ceylon Citronella respectively (Dutta *et al.*, 2016). Essential oil of *Cymbopogon* species are extensively used in flavour, fragrances, soaps, detergents, cosmetics and perfumery industries (Wany *et al.*, 2014) and it is known to possess anti-bacterial, anti-fungal, insecticidal and insect repellent activities for prolonged period.

Environment is not being static so every organism attempts to withstand the environmental variations through individual or population adaptability (Chauhan *et al.*, 2015). Generally, the essential oil yield variation among the cultivars may be due to genetic makeup of individual species (Suvera *et al.*, 2015) and also by their performance in various environments over different seasons in a given location or different locations; therefore performance of genotypes related to stability is a pre-requisite and must be studied (Gupta *et al.*, 2015). But some genotypes react differently in different environments while few genotypes exhibit same characters over a wide range of environments. Hence, to get control of these demerits, many biometric approaches for stability analysis were initiated.

It is verychallenging high yield for the plant breeder to develop a genotype that has good and stable performance throughout different environmental conditions. G × E interaction is the outcome of changes in genotypes relatively across the seasons and also due to differential comeback of the genotypes to various biotic and abiotic factors. Hence, it is required to determine the impact of G × E interaction on each trait studied so that it can be minimized to get a characteristic performance of genotypes. Various methods were introduced for analysis of G × E interaction and its quantification. Among them Additive Main effect and Multiplicative Interaction (AMMI) model analysis is widely used because of its easy interpretation of interactions in graphical representation (1966)through biplots. In the present study, Eberhart and Russell method and AMMI model analysis were performed for the comparison of the results and to find the appropriate high yielding and stable genotypes. Earlier stability works were performed in lemongrass and other species of *Cymbopogon* (Munda *et al.*, 2020), but little scientific reports are present for Citronella so far. Therefore, this study will help in formulating the breeding programme of *C. winterianus* for development of high yielding genotypes having phenotypic stability for different characteristics in a wide range of environments.

Keeping the above view, the study was undertaken to evaluate seven genotypes of *C. winterianus* for their stability and adaptability in essential oil yield and its related traits for four different seasons under the agro-climatic conditions of Meghalaya.

MATERIALS AND METHODS

Collection and planting of the germplasm

The experimental material were selected after initial their screening of 12 genotypes of *Cymbopogon winterianus* based on growth traits and herbage yield. Out of them, Jalapallavi, Bio-13 and Mandakini genotypes were obtained from Central Institute of Medicinal and Aromatic Plants, Lucknow, U.P. and the genotypes JC-1, JC-2, JC-4 and JC-5 were from North East Institute of Science and Technology, Jorhat, Assam were subjected to further intensive study. These genotypes were planted at the experimental farm of College of Post Graduate Studies in Agricultural Sciences, Umroi Road, Umiam, Meghalaya located at an altitude of 950 m above the mean sea level and at geographical co-ordinates 25°402 513 N latitude and 91°542 393 E longitude. The experimental soil was clay loam in texture with pH of 5.21. The available nutrients *viz*., nitrogen, phosphorus and potassium were 284.15, 18.30, 230.17 kg/ha respectively. The meteorological parameters observed during experimentation were presented in Fig. 1.

Randomized Block Design (RBD) with four replications and each genotype was allotted randomly to the seven plots of each replication. The total plot size was 2.0 m x 2.0 m with uniform spacing of row to row 50 cm and plant to plant 40 cm was followed. The recommended dose of nutrients (@ 80 N, 60 P_2O_5 and 40 K_2O kg/ha) and FYM (@ 25 tonnes/ha) was applied. The farm yard manure along with the complete dose of P_2O_5, K_2O and two-third of nitrogen were applied as basal dose after each cutting while the remaining one-third of nitrogen was top dressed after 30 days of each cutting. Weeding, irrigation and other standard package of practices were followed to raise a healthy crop.

Essential oil extraction

The transplanting of the stem slips was done during August, 2018 and followed by phase of harvesting as 1st Cutting: February, 2019, 2nd Cutting: June, 2019, 3rd Cutting: October, 2019 and 4th Cutting: February, 2020. Here, August, 2018 - February, 2019 (S1); February, 2019 - June, 2019 (S2); June, 2019 - October, 2019 (S3) and October, 2019 - February, 2020 (S4) represented as four different seasons. Extraction of essential oil was done from shade dried herbage by using Clevenger apparatus as per standard protocol (Clevenger, 1928). The freshly harvested herbage was shade dried for 24-48 hrs to reduce moisture content and filled it in the round bottomed flask in 1:8 ratio of shade dried herbage (chopped into small pieces of 1 kg per each samples) and water, than subjected to hydro distillation for 2-3 hrs at 100°C. The oil recovered was stored in amber colored bottles under room temperature until further use.

Statistical analysis

The data collected from five randomly selected plants of each genotype in each replication for 12 traits were averaged and pooled for further biometrical analysis. The stability of each genotype was calculated by Eberhart and Russell (1966) method and AMMI model analysis. The stable genotype, as defined by Eberhart and Russell (1966) is one with high mean (X_i), unit regression coefficient ßi = 1 on an environmental index (I_j) and least square deviation from regression (S^2_{di} = 0). The linear regression model suggested by Eberhart and Russell (1966) is given below,

$$Y_{ij} = \mu_i + ß_i I_j + S_{ij}$$

Where, Y_{ij} = Mean performance of the ith genotype in the jth environment

μi = Mean of the ith genotype overall the environments

ßi = Regression coefficient which measures the linear response of the ith genotype of varying environments

S_{ij} = Deviation from linear regression of ith genotype in jth environment

I_j = Environmental index obtained as the mean of all varieties at the jth environment minus the grand mean.

On the other hand, AMMI biplot analysis (Gauch, 2006) was used to represent G x E patterns since it involves both additive and multiplicative components in analysis. By using AMMI biplot analysis, the genotypes can be differentiated on the basis of their performance over the seasons/years (Mukherjee *et al*., 2013). It is also user-friendly in the selection of stable genotypes with wide scale adaptability in distinct environments because G × E influences the genetic gain as a result important for plant breeding programme (Bhagwat *et al*., 2018). The interaction effect can be analyzed using principal components axis (IPCA1 and IPCA2). AMMI model analysis was done for yield and its related traits in *Cymbopogon* to check the G × E interaction and stability.

RESULTS AND DISCUSSION

Pooled ANOVA for seven Citronella genotypes

The pooled analysis of variances in Table 1 showed the significant differences among the genotypes studied revealing that sufficient variability is present for the different characters and selection would be effective to develop the varieties with desired forms of crop plants (Dhanwani *et al*., 2013). Similarly the difference due to mean sum of square due to environments were highly significant for all the traits indicating that the environment over the seasons had highly influences the performance of genotypes for traits under study. G × E interaction should be considered for selecting a good performing genotype (Singh *et al*., 2009). G × E interaction is considered by many statisticians and by plant breeders for selection of good performing genotypes (Freeman, 1973). The G × E interaction was significant for all the traits except plant height and leaf width, which shows differential response of genotypes in variable seasons. Similar result was also reported by Admassu *et al.* (2008).

The mean sum of squares due to G x E interactions were

Table 1: Pooled ANOVA for stability parameters for 12 traits in seven Citronella genotypes (Eberhart and Russell, 1966)

Source of variation	Degrees of freedom	Plant height (cm)	Leaf length (cm)	Leaf width (cm)	Leaf area index	Number of tillers per clump	Number of leaf per clump	Petiole length (cm)	Fresh herbage weight per clump (g)	Shade dry weight per clump (g)	Fresh biomass yield per plot (kg)	Dry bio mass yield per plot (kg)	Essential oil yield (ml/kg)
Environments	3	5554.99**	870.48**	1.24**	1333.90**	4347.61**	111372.09**	60.35**	1261793.00**	808449.10**	71.45**	52.41**	40.32**
Genotypes	6	1013.06**	310.18**	0.05**	638.41**	416.92**	21001.19**	64.67**	91661.50**	73684.27**	6.34**	4.26**	2.91**
G x E	18	126.59	101.76*	0.01	135.58*	262.15**	6562.43**	33.19**	15751.09**	12590.16**	1.00**	0.86**	0.96*
E (linear)	1	16664.98**	2611.45**	3.70**	4001.70**	13042.83**	334116.26**	181.05**	3785378.00**	2425347.00**	214.34**	157.22**	120.95**
G x E (linear)	6	85.1	123.40*	0.02*	58.82	90.78	2766.03	71.78**	22087.09**	26821.38**	1.57**	1.66**	0.56
Pooled deviation	14	126.29	77.95	0	149.11*	298.14**	7251.96**	11.92	10785.5	4692.47	0.61*	0.4	1.00*
Pooled error	81	118.54	52.44	0.01	68.51	79.33	2764.36	10.66	6113.74	4856.54	0.31	0.24	0.45

Table 2: Stability parameters of seven Citronella genotypes for yield related characters across seasons

Genotypes	Plant height (cm)			Leaf length (cm)			Leaf width (cm)			Leaf area index			Number of tillers per clump			Number of leaves per clump		
	Mean	ßi	S^2di	Mean	ßi	S^2di	Mean	ßi	S^2di	Mean	ßi	S^2di	Mean	ßi	S^2di	Mean	ßi	S^2di
Jalapallavi	94.73	1.06	-24.71	68.47	0.94	28.59*	1.61	0.61	0	34.16	0.79	-2.96	62.15	1.03	52.28*	291.99	0.95	974.83
Bio - 13	94.39	0.87	-19.74	66.59	1.11	-11.77	1.6	1.03	0	33.48	1.05	1.73	58.99	1.08	40.2	290.76	1.06	691.87
Mandakini	110.94	1.17	45.97	68.28	0.93	34.11*	1.71	0.99	0	46.34	1.07	52.66*	71.85	1.36	4.35	366.84	1.38	-86.98
JC-1	94.15	0.85	35.95	63.13	0.67	-10.99	1.58	0.98	0	30.89	0.66	-15.23	57.18	0.71	-6.23	287.74	0.71	-350.52
JC-2	106.12	0.85	-29.5	70.85	2.1	-5.22	1.71	1.17	0	39.05	1.57	82.52**	60.84	0.79	248.32**	299.23	0.76	5908.77**
JC-4	112.07	1.32	1.12	77.45	1.05	15.79	1.63	1.03	0	46.47	1.16	34.11	66.81	0.91	59.92*	341.83	0.92	1286.31
JC-5	105.36	0.87	4.46	68.28	0.19	-5.87	1.59	1.18	0	42.18	0.69	-11.78	66.04	1.13	-15.93	365.77	1.23	-570.97
Grand mean	102.54			69.01			1.63			38.94			63.41			320.59		
C.D. at 0.05	18.25			14.34			0			19.83			28.05			138.33		

Genotypes	Petiole length (cm)			Fresh herbage weight per clump (g)			Shade dry weight per clump (g)			Fresh biomass yield per plot (kg)			Dry biomass yield per plot (kg)			Essential oil yield (ml/kg)		
	Mean	ßi	S²di	Mean	ßi	S²di	Mean	ßi	S²di	Mean	ßi	S²di	Mean	ßi	S²di	Mean	ßi	S²di
Jalapallavi	16.83	3.71	-0.23	332.31	1.02	935.13	272.38	1.04	-647.39	1.76	0.56	0.12	1.33	0.49	0.12	10.18	0.89	0.52**
Bio - 13	16.44	-0.36	-1.85	302.94	0.78	-1339.66	253.81	0.87	-1011.93	2.8	1.14	0.07	2.29	1.13	0.02	10.27	0.91	-0.05
Mandakini	20.09	1.54	2.46	441.25	1	3002.87	367.06	0.97	511.69	3.37	1.17	-0.01	2.66	1.14	-0.02	9.92	0.98	0.28*
JC-1	17.32	1.97	-0.04	351.88	0.84	6716.9	263.13	0.73	2823.7	2.57	0.82	0.07	2	0.75	0.01	10.4	1.25	0.01
JC-2	20.73	1.5	2.25	387.19	0.87	-596.23	305.69	0.75	-640.79	3.46	1.09	0.13	2.77	1.14	0.08	9.65	0.73	0.1
JC-4	20.28	-1.11	-1.1	493.31	1.38	27.39	419.38	1.55	-675.84	3.39	1.1	0.16	2.66	1.21	0.09	9.9	1.05	0
JC-5	21.09	-0.24	0.71	486.51	1.11	-570.82	395.13	1.1	-646.56	3.38	1.12	-0.01	2.59	1.14	-0.03	9.62	1.19	0.1
Grand mean	18.97			399.34			325.22			2.96			2.33			9.89		
C.D. at 0.05	5.61			168.69			111.27			1.27			1.03			1.62		

assessed against pooled error to determine significant effects of genotype and environment independently. The outcomes due to environments (linear) were highly significantly for all the traits studied indicating additive environmental variance. The variance due to G x E (linear) was significant for all the traits except for plant height, leaf area index, number of tillers per clump, number of leaves per clump and essential oil yield. This shows that only non-linear components will be accountable for G × E interaction (Lal *et al.*, 2018). The pooled deviation was also found to be significant for leaf area index, number of tillers per clump, number of leaf per clump, fresh biomass yield per plot and essential oil yield. This shows the deviation in the linear graph for the performance of the genotypes of respective significant traits to the environments.

Stability analysis using Eberhart and Russell model

The regression coefficient ($ß_i$), mean square deviation from regression line (S^2_{di}) and mean performance (μ) were calculated for each genotype and presented in Table 2. The environmental additive indices (I_j) of different seasons for all the traits studied were expressed as deviation from grand mean as shown in Table 3.

The average performance of the plant height ranged from 94.15 cm to 112.07 cm with an average value of 95.22 cm. JC-2 and JC-5 were good performing genotypes for plant height, while JC-2 was above average and stable for plant height specifically adapted to unfavorable season whereas JC-4 was specifically adapted in favorable seasons. The performance of the genotypes for leaf length from stability analysis ranged from 63.13 cm in JC-1 to 77.45 cm in JC-4. Among seven Citronella genotypes studied, JC-4 genotype was considered as good performing and stable for leaf length, whereas JC-2 genotype had $ß_i > 1$ which indicates that it will be specifically adaptable in favorable seasons. According to static concept, whereas in dynamic concept proposed by Eberhart and Russell (1966), the genotype is said to be stable only if it shows high mean performance, regression coefficient equal to 1 (ßi = 1) and deviation from regression (S^2_{di} ~0) as low as possible. From Table 2, the genotypes JC-4 and JC-5 were showing stable and good performance for number of tillers per clump, while Mandakini was better adaptable to all the seasons.

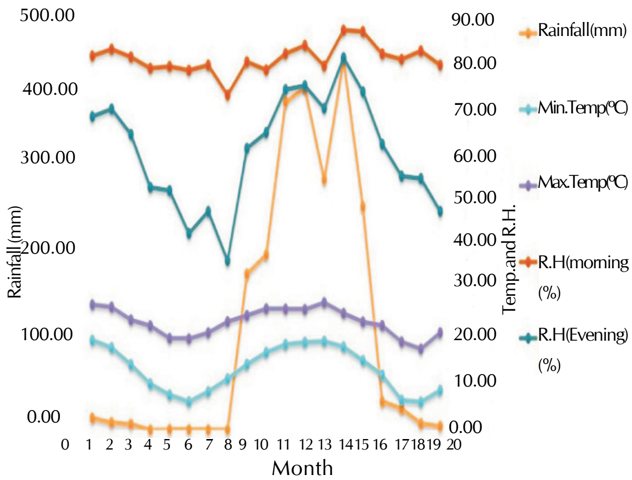

Figure 1: Meteorological data (Temperature, rainfall and relative humidity) during the crop season (August, 2018 to February, 2020)

Table 3: Estimation of environmental additive effects (Ij) for 12 traits in four seasons expressed as deviation from grand mean

Traits under study	S1	S2	S3	S4	Grand mean
Plant height (cm)	-9.91	14.65	9.27	-14.01	102.54
Leaf length (cm)	-3.32	2.37	6.65	-5.7	69.01
Leaf width (cm)	0.23	-0.24	-0.1	0.11	1.63
Leaf area index	-6.38	-0.19	9.63	-3.07	38.94
Number of tillers per clump	-15.58	6.76	12.74	-3.91	63.41
Number of leaves per clump	-78.59	34.54	64.41	-20.36	320.59
Petiole length (cm)	-1.27	-1.21	0.87	1.62	18.97
Fresh herbage weight per clump (g)	-215.59	269.06	59.55	-113.02	399.34
Shade dry weight per clump (g)	-167.37	222.49	34.03	-89.15	325.22
Fresh biomass yield per plot (kg)	-1.88	1.93	0.42	-0.47	2.96
Dry biomass yield per plot (kg)	-1.55	1.65	0.43	-0.53	2.33
Essential oil yield (ml/kg)	1.48	0.11	-1.44	-0.14	9.89

Table 4: AMMI model's ANOVA table for seven Citronella genotypes

Source of variation	DF	Plant height (cm)		Leaf length (cm)		Leaf width (mm)		Leaf area index		Number of tillers per clump		Number of leaves per clump	
		MS	% Explained	MS	% Explained	MS	% Explained	MS	% Explained	MS	% Explained	MS	% Explained
ENV	3	5554.99**	66.6	870.48**	41.42	1.23**	88.62	1333.90**	38.96	4347.61**	64.37	111372.09**	57.78
GEN	6	1013.06**	24.29	310.18**	29.52	0.05**	7.11	638.41**	37.29	416.92**	12.35	21001.19**	21.79
G × E	18	126.59	9.11	101.76*	29.06	0.01	4.27	135.58*	23.76	262.15**	23.29	6562.43**	20.43
PC1	8	198.79	69.79	95.89	41.88	0.02*	75.64	174.82*	57.31	458.87**	77.8	11267.45**	76.31
PC2	6	87.86	23.13	113.88	37.3	0.01	17.63	128.04	31.48	149.15	18.97	3842.35	19.52
Residuals	84	132.01	0	58.11	0	0.01	0	82.63	0	82.8	0	2956.05	0

Table 4(Continued): AMMI model's ANOVA table for seven Citronella genotypes

Source of variation	DF	Petiole length (cm)		Fresh herbage weight per clump (g)		Shade dry weight per clump (g)		Fresh biomass yield per plot (kg)		Dry biomass yield per plot (kg)		Essential oil yield (ml/kg)	
		MS	% Explained	MS	% Explained	MS	% Explained	MS	% Explained	MS	% Explained	MS	% Explained
ENV	3	60.35**	15.52	1261792.67**	81.95	808449.06**	78.39	71.45**	79.29	52.41**	79.28	40.32**	77.66
GEN	6	64.67**	33.26	91661.50**	11.91	73684.27**	14.29	6.34**	14.07	4.26**	12.9	2.91**	11.23
G × E	18	33.20**	51.22	15751.09*	6.14	12590.16*	7.32	1.00**	6.64	0.86**	7.82	0.96*	11.11
PC1	8	54.06**	72.37	17514.64**	49.42	21509.80**	75.93	1.65**	73.61	1.62**	83.8	1.34**	61.74
PC2	6	20.82	20.91	21625.53**	45.77	7689.66	20.36	0.70*	23.34	0.35	13.48	0.91	31.37
Residuals	84	11.06	0	7593.35	0	5948.76	0	0.35	0	0.27	0	0.49	0

Jalapallavi, JC-2 and JC-4 genotypes exhibited significant regression deviation suggesting the existence of non-linear G × E interactions. The existence of significant level of regression coefficient while resolving the data shows its usefulness in analysis. Among the seven Citronella genotypes studied, Mandakini was specifically adapted in favorable seasons while JC-4 and JC-5 genotypes showed stable and exceptional performance in all seasons for number of leaves per plot.

For shade dry weight per clump, the mean performances of genotypes ranged from 253.81 g in Bio-13 to 419.38 g in JC-4 with a population mean of 325.22 g. Here, based on ß values, Mandakini and JC-5 showed good performance and stability in all seasons (ß = 1) while JC-4 showed above average response (ß > 1) specifying their general adaptability and fitting for favourable seasons. In case of fresh biomass yield per plot, JC-4, Mandakini, JC-5 and JC-2 were observed as stable and good performing genotypes for all seasons.

The stability analysis for essential oil yield over four seasons showed that the mean performance of genotypes ranged from 9.62 $mlkg^{-1}$ in JC-5 to 10.40 $mlkg^{-1}$ in JC-1. The genotypes JC-1 and Jalapallavi had better adaptability to the favourable seasons while Bio-13, Mandakini and JC-4 were considered as stable and good performing genotypes for essential oil yield in different environmental conditions as they showed high mean value,ß = 1 and $S^2_{di} \leq 0$. Based on the traits studied, different stable and high yielding genotypes were identified. The performance of genotypes Mandakini and JC-4 exhibited a tendency to remain stable in all the seasons regardless of variable environmental conditions.

Additive Main Effects and Multiplicative Interaction Model (AMMI) Analysis

The AMMI model analyzes multiple environmental impacts on detection of G × E interaction (Yan and Tinker, 2006) along with accurate identification of genotypes for traits under study. The ANOVA of AMMI model for seven genotypes showed that the genotypic and seasonal effects were significant for all the traits studied (Table 4). Non significant effect of G × E interaction observed in plant height and leaf width reveals the resemblance of genotypes across different seasons. Whereas, significant effects of G × E interaction in essential oil yield and rest of the traits shows that the performance of the genotypes due to different seasons were varied. As a result, precise interpretation of the significant traits is required to follow through an effective selection and development of genotypes.

Earlier in *Cymbopogon*, AMMI model was used in analysis of G x E interaction for selection of stable and high essential oil yielding genotype over the environments (Lal, 2012). The G x E interaction effects analyzed using AMMI ANOVA explained the percent of G × E interaction sum of squares *i.e.*, 29.06 %,

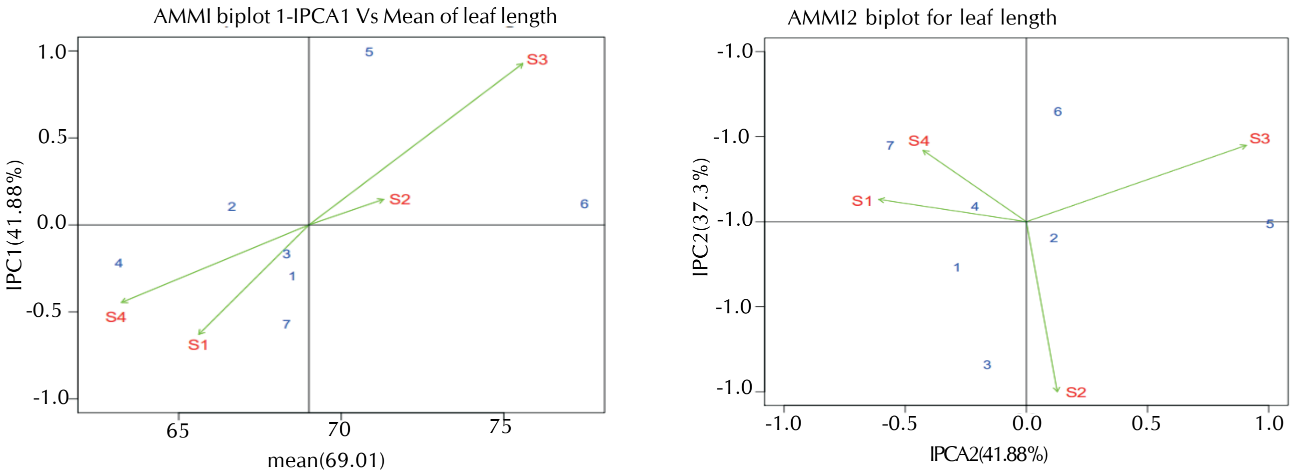

Figure 2: AMMI 1 and 2 biplots for leaf length of the seven citronella genotypes for four seasons.

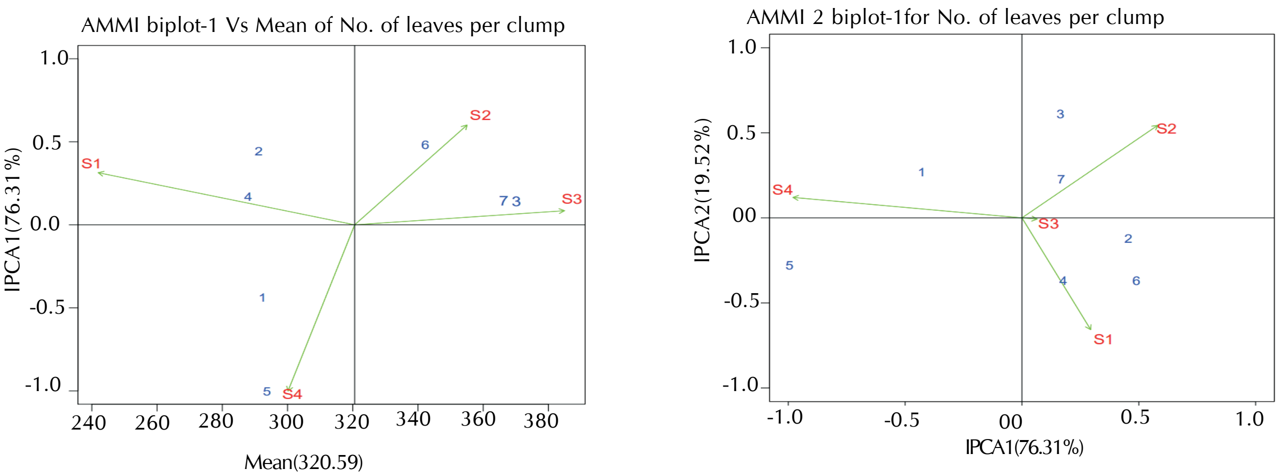

Figure 3: AMMI 1 and 2 model biplot for number of leaves per clump of the seven citronella genotypes for four seasons

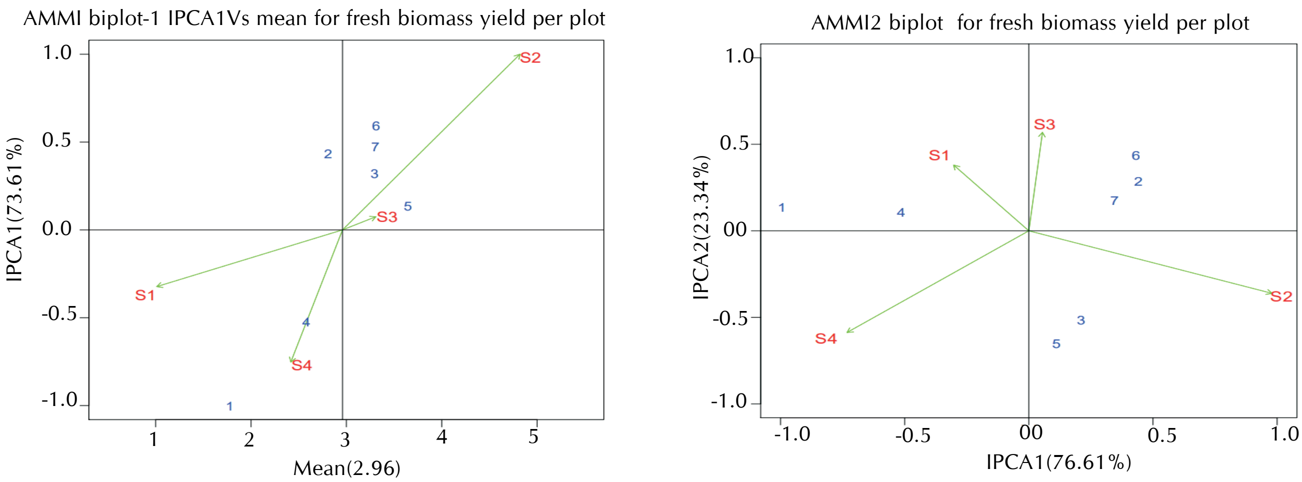

Figure 4. AMMI 1 and 2 model biplot for fresh biomass yield per plot of the seven citronella genotypes for four seasons.

20.43 %, 6.64 % and 11.11 % for leaf length, number of leaves per clump, fresh biomass yield per plot and essential oil yield respectively as presented in Table 4. The low G × E interaction verifies the stability performance of the genotypes for different traits in varied environments. However, high G × E interaction may be fruitful in some environments (Nath And

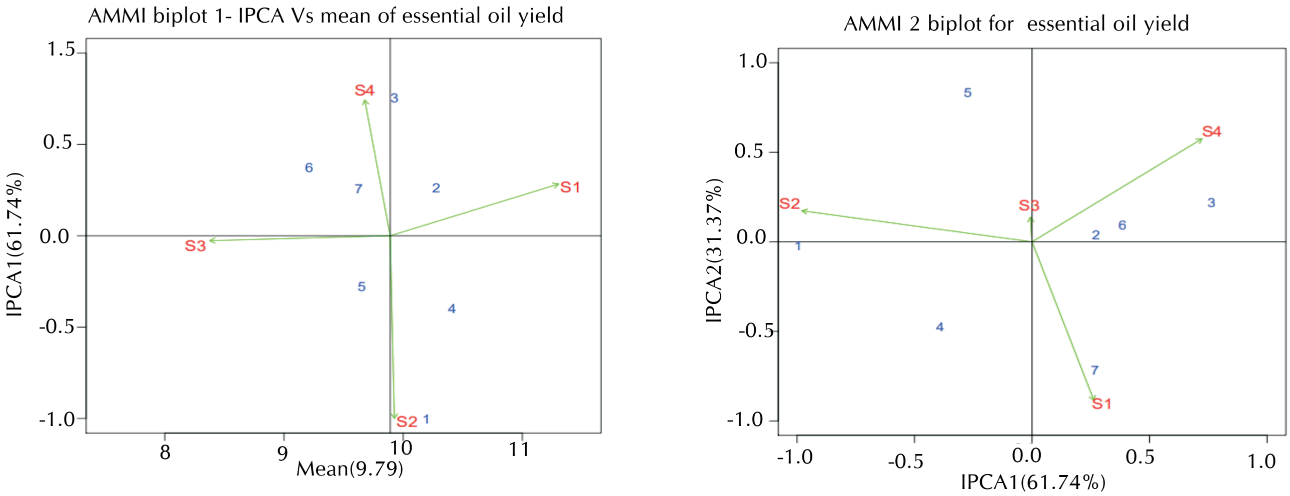

Figure 5: AMMI 1 and 2 model biplot for essential oil yield of the seven citronella genotypes for four seasons

Dasgupta, 2013). The genotypes placed in the locality near biplot origin are regarded to be average adaptable (Murphy *et al.*, 2009). For all the traits, unfamiliar winning genotypes were recognized in various sectors, and hence give substance for presence of G × E interaction.

The AMMI biplots of leaf length (Fig. 2) showed that the genotypes Mandakini and Jalapallavi were unstable across all the seasons due to dispersed positions from the origin, whereas JC-2 and Bio-13 were seen to be broadly adapted and more stable genotypes. S3 and S2 were relatively stable and better performing seasons for leaf length. In case of number of leaves per clump biplots (Fig. 3), Mandakini had the highest number of leaves per clump but highly unstable in nature. The genotypes JC-4 and JC-5 was highly stable with higher number of leaves per clump since the IPCA1 (76.31 %) value was near to the origin and hence it shows negligible interaction across all the seasons. S2 and S3 were relatively stable seasons with higher number of leaves per clump. The distinct interactions were noticed as it may be due to different genetic constitution of the genotypes and also due to seasonal variations (Banik *et al.*, 2010).

From the AMMI biplots of fresh biomass yield per plot (Fig. 4), the genotypes Mandakini, JC-2, JC-4 and JC-5 had higher fresh biomass yield per plot. The performance of Jalapallavi and JC-2 were the most variable across the seasons as they were away from the bilpot origin when plotted between IPCA1 (73.61 %) and IPCA2 (23.34 %). The genotypes Mandakini, JC-4 and JC-5 were highly stable with higher fresh biomass yield per plot. In case of essential oil yield biplots (Fig. 5), JC-1, Bio-13 and Jalapallavi were identified as the high essential oil yielding genotypes but they were highly unstable in nature. Therefore, their performance is very unpredictable and cannot be considered for commercial cultivation. However, genotypes like Mandakini and JC-4 were broadly adapted and more stable as they were near to the biplot origin when plotted between IPCA1 (61.74 %) and IPCA2 (31.37 %). Hence they can be believed as ideal genotypes for essential oil yield.

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