Journal of Medicinal Plants Studies
www.PlantsJournal.com

ISSN (E): 2320-3862
ISSN (P): 2394-0530
NAAS Rating: 3.53
www.plantsjournal.com
JMPS 2021; 9(2): 132-140

Received: 14-01-2021
Accepted: 17-01-2021

Raj Kishori Lal
Division of Plant Breeding and Genetic Resource conservation, CSIR- Central Institute of Medicinal and Aromatic Plants, P.O. CIMAP, Lucknow, Uttar Pradesh, India

Pankhuri Gupta
[2]CSIR- Human Resource Development Centre Campus, Academy of Scientific and Innovative Research (AcSIR), Uttar Pradesh, India
[3]Department of Bio-Technology, Development Centre Campus, Academy of Scientific and Innovative Research (AcSIR), Uttar Pradesh, India

Anand Mishra
Division of Plant Breeding and Genetic Resource conservation, CSIR- Central Institute of Medicinal and Aromatic Plants, P.O. CIMAP, Lucknow, Uttar Pradesh, India

Corresponding Author:
Raj Kishori Lal
Division of Plant Breeding and Genetic Resource conservation, CSIR- Central Institute of Medicinal and Aromatic Plants, P.O. CIMAP, Lucknow, Uttar Pradesh, India

Performance evaluation of advanced generation and stable genotypes selection using GGE biplot model in pyrethrum (*Tanacetum cinerariifolium* Sch. Bip.)

Raj Kishori Lal, Pankhuri Gupta and Anand Mishra

Abstract
This study's aims were to determine the extent of genetic and environment interaction for dry flower yield and pyrethrins contents in the flowers, identify superior pyrethrum genotypes for yield in different years, and determine an ideal year/environment for pyrethrum breeding programmes in India. The experiments were conducted for four years, 2015-2016 to 2018-2019. Ten newly advanced generation pyrethrum genotypes and one commercial variety (CIM Avadh) were evaluated in a RBD design. A pooled analysis of variance over the environments/years was cundected for flower yield and pyrethrin contents (%). The results depicted the significant ($p<0.01$) differences for all the characters. The results for pyrethrins content (%) also depicted significant differences. The fresh × dry flower yield; pyrethrin I × jasmolin I (%); pyrethrin I × pyrethrins (%) were found highly and positively associated ($p>0.01\%$) while, the traits pyrethrin II × jasmolin II and Jasmolin I × pyrethrins (%) found significant and positively associated ($p>0.05\%$) each other across all four years/environments. Therefore, selecting these traits will be beneficial according to correlations over the selective environments/years. The biplot analysis explained the advanced generation pyrethrum genotypes G9, followed by G1, and G3 for the dry flower yield g/plot and genotypes, namely G1, followed by G4 and G3 for the pyrethrins content (%) were high yielding and stable over years/environments.

Keywords: G × E interaction, insecticides, para-medicinal, pyrethrins, synthetic pyrethroids, stability

1. Introduction
Pyrethrum (*Tanacetum cinerariifolium* Sch. Bip.), family 'Asteraceae' is vital for its natural pesticidal compounds (pyrethrin I, II; cinerin I, II; jasmolin I, II) known as the pyrethrins. Combining the all above components responsible for the kill and knockdown of insects i.e. insecticidal properties of pyrethrum extract (Singh, S.P., 1988; Lal *et al*., 2020a, b, c, 2021) [22, 11, 12, 14]. The pyrethrins are mainly concentrated in the flower heads of the pyrethrum. It is growing in Europe, South America, Japan, South East Asia, Kenya, and India (Huasin *et al*., 1988; Singh, 1988) [22]. Presently Kenya, Rwanda, Tanzania, and Tasmania are the significant pyrethrum source, accounting for more than 65 % of the world production (Lal *et al*., 2019; 2020a, b, c, 2021) [11-12-14].
Presently, limited improved pyrethrum varieties restrict progress in this crop (Lal *et al*. 2010; 2019; 2021; Sarkar, 2021) [13, 15]. Due to self-incompatibility by cross-pollination to get fertile seeds depends on pollinator insects, like honey bees, butterflies and ants, etc. To make its cultivation cost-effective in India, requires high yielding stable genotypes as varietal development. We examined the yield performance of some genotypes of pyrethrum to understand the stability performance by GGE biplot (Yan and Tinker, 2006) [30] analysis of various yield components including pyrethrins percent.

2. Materials and Methods
Pyrethrum Seeds **(***Tanacetum cinerariifolium* Sch. Bip.**)** of the ten advanced generation genotypes/mutant (M7) were isolated using γ- rays at doses of 20 - 300 Gy (source ^{60}Co) during 2011 (Lal *et al*., 2021a) on the variety Avadh were grown for the four consecutive years (2015-16, 2016-17, 2017-18, and 2018-19) in a field evaluation trial applying the RBD in three replications (plots size = 12m^2) for the advance generation performance analysis. The research farm site was located at the CSIR-CIMAP, Lucknow, India at 26.5 ˚N latitude; 80.50˚E.

longitude; 120 m above MSL: climate semiarid-subtropical. The crops received normal cultural operations (four weddings), four irrigations, and fertilizer in the ratio of 100 kg N: 60 kg P_2O5: 40 kg K_2O./ha). The FYM was also applied to 15 trolleys at the time of fie preparations.

2.1 Morphological analysis
Metric observations were recorded on fresh flower, and dry flower yield/plot (g), and chemical constituents in the dry flower powder: pyrethrin I, II; jasmolin I, II; cinerin I, II and pyrethrins content in percent.

2.2 Chemical analysis
Flowers of pyrethrum were plucked and air-dried in the shade, and 1 g air-dried flowers were used for pyrethrins extraction in a soxhlet apparatus for six h with 100 mL *n*-hexane (40◦–60◦C) and evaporated. The residue was treated with 10 mL acetonitrile for HPLC analysis. Pyrethrins were estimated through a reverse-phase HPLC using a slightly modified method reported earlier (Wang *et al*., 1997; Haque *et al*., 2007) [26, 5]. The binary gradient HPLC analysis was carried out on an LC-10AD Shimadzu, Kyoto, Japan liquid chromatography equipped with a μ Bondapak C18 (300 mm × 3.9 mm) column (Waters) and a photodiode array detector SPD-M10 Avp, Shimadzu. The eluting solvent system (flow rate was 1.4 ml min−1) comprised acetonitrile-water (60:40). Merk, India was used for 15 min followed by a linear gradient for 10 min leading to the solvent composition of acetonitrile-water (80:20), kept on hold for another 10 min. The detection was carried out at λ 225 nm. Pyrethrins concentration was calculated as a mixture of pyrethrin I, II; cinerin I, II; jasmolin I, II concerning standard pyrethrin procured from Sigma-Aldrich, USA as pyrethrins technical mixture, PESTANAL (HPLC assay 21.58%). Standards and sample extracts were stored at –4 ˚C in a deep freezer, protected from heat and light.

2.3 Statistics
Morpho-metric data were recorded and analyzed on fresh flower, dry flower yield (g/plot), and chemical constituents in the dry flower powder: pyrethrin I, II; jasmolin I, II; cinerin I, II and pyrethrins/HPLC assay percentage. Data of the ten genotypes along with one check var. Avadh from four years were analyses for the stability by GGE biplot model by using 4.0 version software, available in the Division of Plant Breeding and genetic Resource conservation of the Institute based on (Yan, 2002; Yan and Tinker, 2006; Yan *et al*., 2007 and Singh and Chaudhary, 2014) [30, 17] for identifying high-yielding and stable pyrethrum lines. In this study, years were considered as environments.

3. Results
The combined analysis of variance for the eleven traits showed the highly significant (p<0.01%) differences for all components like genotypes, environments/years, and genotypes × environments/years interactions (Table 1). The which-won-where biplot showed different winning genotypes in different environments (Figure 1, a-f). Besides the pooled analysis of variance (ANOVA) analysis, the genetic associations among the economic traits in different environments of pyrethrum also worked out (Table 2).
The GGE biplot analysis was used to determine the mega-environments and visualize the "which-won-where" pattern using the GGE biplot model based on singular value decomposition (SVD) of t principal components were used as per the method of Yan and Tinker (2006) [30].

$$\text{GGE model} = Yij - \mu_i - \beta_j = \sum_{k=1}^{t} \lambda_k \alpha_{ik} \gamma_{jk} + \varepsilon_{ij}$$

Where,
Y_{ij} is the performance of genotype i in environment j, μ is the grand mean; j b is the main effect of the environment; j, k is the number of principal components (PC); λ_k is the singular value of the k^{th} PC; and α_{ik} and γ_{jk} are the scores of i^{th} genotype and j^{th} environment, respectively for PC_k; ε_{ij} is the residual associated with genotype i in environment j.
For mega-environment delineation of test locations, the which-won-where scatter plot was developed by a polygon based on connecting genotypes that are furthest away from the biplot polygon contained all other lines. The polygon was further divided by perpendicular lines drawn to the polygon sides and running from the biplot origin (Yan, 2002; Yan and Tinker, 2006) [30]. The genotypes focused comparison biplot for comparing genotypes based on mean yield. The stability was determined by representing an average environment. A straight line that was dissecting the biplot origin to the average environment coordinate (average genotype axis) was drawn followed by a perpendicular line that passes through the biplot origin using the appropriate singular value partitioning (SVP) methods. The environment vectors were drawn from the location comparison biplot origin to the markers of the environment.

4. Discussion
The pooled ANOVA (analysis of variance) for the eleven traits showed the highly significant (p<0.01%) differences for all components like genotypes, environments/years, and genotypes × environments/years interactions (Table 1). The which-won-where biplot showed different winning genotypes in different environments (Figure 1 a-f). Besides the pooled analysis of variance (ANOVA) analysis, the genetic associations among the economic traits in different environments of pyrethrum also worked out (Table 2). In the GGE biplot model, the GGE biplot and genotype by environment-traits interactions figures were also generated by principal components (Figure 1a-f.). The GGE stands for genotype main effect (G) plus genotype by environment interaction (GE), which is the only source of variation relevant to genotype evaluation. Mathematically, GGE is the genotype by environment data matrix after the environment means are subtracted.
Genetic associations/correlations among economic traits across the years/environments were also showed very interesting results and play a very important role, for example, the traits fresh flower-vs.-dry flower yield/plot (g); pyrethrin I (%)-vs.-jasmolin I (%); pyrethrin I (%)-vs-pyrethrins (%) were found highly and positively associated (p>0.01%) while, the traits Pyrethrin II (%)-vs-jasmolin II (%) and Jasmolin I (%)-vs-pyrethrins (%) found significant and positively associated (p>0.05%) each other across all four years/environments. Similarly, the traits fresh flower yield/plot -vs.- pyrethrin I, jasmolin I, jasmolin II; dry flower yield/plot (g)-vs-pyrethrin I, jasmolin I, jasmolin II (%) were found significant and positively correlated (p>0.05%) in the year I and year III only. The trait Jasmolin I (%)-vs-cinerin II (%) was significant and negatively correlated in the year I but positively correlated in year III, having the unusual behavior. The other characters were depicted the different types of associations in years II and IV, respectively. Hence, selecting these characters will be beneficial according to correlations

over the selective environments/years (Table 2-3).

The biplot was dividing into three parts and four mega-environments and depicted five vertex genotypes. The biplot identified three winning genotypes, namely G9 (520.83), followed by G1 (409.86), G3 (406.51), and lowest G5 (218.25) g/plot for the dry flower yield. Genotypes within the polygon were less responsive than the vertex genotypes (Figure 1(a-f). Based on mean dry flower yield performance and stability, the biplots ranked all genotypes as G9>G1>G3>G6, as ideal genotypes followed by a check variety CIM Avadh (G5) in the advanced generation lines of pyrethrum. Similarly, for the pyrethrins content, the biplot identified three winning genotypes, namely G1 (0.542), followed by G4 (0.494), G3 (0.468), and lowest G5 (0.219) % in the mega-environment. Based on the mean performance and stability of pyrethrins % trait, the biplots ranked G1>G4>G3>G6 as ideal genotypes with comparisons to check variety CIM Avadh (G5). For the fresh flower yield (g/plot), the biplot identified three winning genotypes, namely G1 (1690.33), followed by G9 (1687.50), G3 (1534.83), and lowest G5 (870.56) across the mega-environment. Based on the mean performance and stability of pyrethrins % trait, the biplots ranked G1>G9>G3>G6 as good performing genotypes with comparisons to check G5. The more or less similar trends were expressed by the other six pyrethrins traits (Table 4). The environment-focused comparison showed the ideal test environment was environment II/year II, located near the center of the concentric circles as the most representative testing year/environment, while other test years/environments were not representatives (Figure 1d-f and 2).

The presence of significant genotype main effect and G × E interaction suggested differential responses of pyrethrum genotypes across tested environments. They implied the need to identify high-yielding and stable genotypes across the test environments. Several researchers have reported similar results (Gurmu *et al*., 2009; Tukamuhabwa *et al*., 2012; Atnaf *et al*., 2013; Lal *et al*., 2013, 2014;2020a,b,c; Kumar *et al*., 2014; Bhartiya *et al*., 2017) [25, 11-12-14, 2]. The significant variance component attributed to the environment alone justified the need to use genotype main effect plus G × E interaction (GGE) biplots, in which the GGE biplot captured much of the variation due to genotype plus G × E interaction as a fraction of the total sum of squares (G + E + GE) (Yan *et al*. 2007). The significant variance component due to environments/years depicted that the years/environments used in the present study were very diverse across the years/environments.

The considerable G × E interaction and error variance components found in the present study could reduce selection progress by complicating the identification and recommendation of superior genotypes for a target environment (Nyombayire *et al*., 2018; Hunde *et al*., 2019) [19, 6]. However, the results observed in this study were of a lesser magnitude than that reported by Bhartiya *et al*. (2017) [2], where G × E interaction was almost double the genotypic main effects and five times larger than environmental influences. Significant G × E interaction and residuals observed in multi-environment trials (MET) affect the experiment's repeatability (Simion *et al*., 2018) [23]. These could have contributed to the low, broad sense coefficient of genetic determination the number of environments/years increased. Similar results were reported by Gasura *et al*. (2015) [3] in sorghum across environments basis. Gasura *et al*. (2015) [3] and Sousa *et al*. (2018) [24] suggested that considerable G × E interaction and error variance components increase the cost of variety evaluation due to increased numbers of replications, locations, and seasons needed to improve lines. Since, crop growing locations have no precisely stated demarcations. Most farmers tend to influence each other in the variety that is grown (Gasura *et al*., 2015) [3]. The development of varieties adapted to a broad range of environments is strongly recommended rather than environment-specific varieties (Bhartiya *et al*., 2017) [2].

The significant difference for dry flower yield and related traits observed among genotypes across environments indicated genetic and environmental causes of variation. The significant G × E interaction observed in this study also showed the significance of environmental effects in the expression pyrethrum for the dry flower yield and pyrethrins content. These results are inconsistent with other researchers' findings (Tukamuhabwa *et al*., 2012; Atnaf *et al*., 2013; Lal *et al*., 2013; 2014; 2020a,b,c; Lal *et al*., 2021; Krisnawati and Adie, 2018; Hunde *et al*., 2019) [25, 11, 12, 14, 6, 8]. The results obtained from this study showed that there was limited genetic variation among the test genotypes for the related pyrethrins content (pyrethrin I, II; jasmolin I, II and cinerin I and II contents (%). Therefore, there is no need to advance this set of genotypes targeting the improvement of these traits alone. Based on scatter biplot for mega-environments delineation, only four mega-environments with their winning genotypes located at the polygon's vertices were identified. Low yielding in genotypes might be the gradual changes in biotic and abiotic factors from season to season. The existence of crossover G × E interaction in this study indicated that genotypes evaluation and recommendation typically based on any single location was unreliable because there is the differential response of genotypes across locations (Mare *et al*., 2017) [18]. The presence of crossover interactions indicated genotype evaluation should be based on mean performance and stability (Yan and Kang, 2002) [28].

The presence of G × E interaction for dry flower yield, pyrethrins content, and other related traits, dry flower yield justifies undertaking mega-environments during genotypes selection and recommendations (Krisnawati and Adie, 2018) [8]. Based on the test location biplot, the biplot's vector length approximates the standard deviation within each year/environment and a measure of the location's discriminating ability (Yan and Tinker, 2006) [30]. The years/environments I, II, and III, which had the most extended vectors from the biplot origin, were the most discriminating testing locations. Therefore these three testing locations could be used jointly as biased years to test early-generation breeding materials (Yan *et al*., 2007; Yan and Tinker, 2006) [30]. Discriminating and representative test years/environments help select superior genotypes while eliminating inferior ones.

In a nutshell, the biplot identified three winning genotypes, namely G9 (520.83), followed by G1 (409.86), and G3 (406.51) g/plot for the dry flower yield across the years/environments. For the pyrethrins content, the biplot identified three winning genotypes, namely G1 (0.542), followed by G4 (0.494) and G3 (0.468) % over the years/environments. These genotypes may be recommended for the extensive area cultivation for the pyrethrum.

Table 1: ANOVA table for genotype × Year traits interaction data related to the stability analysis in pyrethrum

Sources	DF	Mean sum of squares (mss)								
		Fresh flower yield/ plot (g)	Dry flower yield / plot (g)	Pyrethrin I (%)	Pyrethrin II (%)	Jasmolin I (%)	Jasmolin II (%)	Cinerin I (%)	Cinerin II (%)	Pyrethrins (%)/HPLC Assy
Block over years	8	15006.30	1352.00	0.001	0.0013	0.000007	0.000000123	0.000007	0.00000106	0.001
Genotypes	10	749320.90**	75051.30**	0.057**	0.1222**	0.000109**	0.000017**	0.000699**	0.000165**	0.098**
Year/Env.	3	824382.20**	31860.00**	0.015**	0.0273**	0.000004**	5.666667**	0.005628**	0.00055**	0.070**
Genotype × Yr	30	697886.10**	62025.30**	0.021**	0.0757**	0.000018**	0.000002**	0.000408**	0.000042**	0.027**
Error	80	8767.78	501.36	0.001	0.0098	0.0000009	0.0000005	0.000003	0.000001	0.001
Total	131									
Grand Mean		1316.75	360.62	0.280	0.085	0.012302	0.00373	0.0158	0.0106	0.418
Std Error		93.64	22.39	0.022	0.011	0.000972	0.000706	0.00169	0.000997	0.032
CV %		7.11	6.21	7.970	12.96	7.90	18.92	10.63	9.43	7.940
LSD (0.05)		156.35	37.39	0.037	0.019	0.001622	0.00118	0.00281	0.00166	0.054
G/GGE		0.15	0.17	0.315	0.447	0.507933	0.502942	0.222269	0.310054	0.375
G/GGY		0.26	0.29	0.479	0.617	0-673681	0.669276	0.363689	0.473345	0.545

**-*p*<0.01; CV = Coefficient of variation

Table 2: Genetic associations among selected traits in different environments of pyrethrum

Associations amongst traits	ENV1	ENV2	ENV3	ENV4	Mean
Fresh flower-vs-dry flower yield/plot (g)	0.976**	0.96**	0.98**	0.95**	0.97**
Fresh flower yield/plot -vs-pyrethrin I (%)	0.687*	0.12	0.69*	0.18	0.42
Fresh flower yield/plot -vs-pyrethrin II (%)	0.428	0.26	0.43	0.27	0.35
Fresh flower yield/plot -vs-jasmolin I (%)	0.648*	-0.09	0.65*	-0.02	0.30
Fresh flower yield/plot -vs-jasmolin II (%)	0.652*	0.08	0.65*	0.08	0.37
Fresh flower yield/plot -vs-cinerin I (%)	-0.240	-0.06	-0.24	-0.17	-0.18
Fresh flower yield/plot -vs-cinerin II (%)	0.027	-0.39	0.03	-0.37	-0.18
Fresh flower yield/plot -vs-pyrethrins (%)	0.800**	0.10	0.80**	0.14	0.46
Dry flower yield/plot-vs-pyrethrin I (%)	0.678*	-0.04	0.68*	0.06	0.34
Dry flower yield/plot-vs-pyrethrin II (%)	0.296	0.22	0.30	0.22	0.26
Dry flower yield/plot-vs-jasmolin I (%)	0.714*	-0.14	0.71*	-0.04	0.31
Dry flower yield/plot-vs-jasmolin II (%)	0.634*	0.11	0.63*	0.11	0.37
Dry flower yield/plot-vs-cinerin I (%)	-0.233	-0.16	-0.23	-0.29	-0.23
Dry flower yield/plot-vs-cinerin II (%)	-0.101	-0.33	-0.10	-0.42	-0.24
Dry flower yield/plot-vs-pyrethrins (%)	0.740**	-0.04	0.74**	0.03	0.37
Pyrethrin I (%)-vs-pyrethrin II (%)	0.014	0.73**	0.14	0.65*	0.42
Pyrethrin I (%)-vs-jasmolin I (%)	0.869**	0.75**	0.87**	0.78**	0.82**
Pyrethrin I (%)-vs-jasmolin II (%)	0.227	0.43	0.23	0.38	0.32
Pyrethrin I (%)-vs-cinerin I (%)	-0.211	-0.32	-0.21	-0.37	-0.28
Pyrethrin I (%)-vs-cinerin II (%)	-0.485	0.08	-0.49	-0.23	-0.28
Pyrethrin I (%)-vs-pyrethrins (%)	0.911**	0.97**	0.91**	0.96**	0.94**
Pyrethrin II (%)-vs-jasmolin I (%)	-0.067	0.49	-0.07	0.44	0.20
Pyrethrin II (%)-vs-jasmolin II (%)	0.663*	0.68*	0.66*	0.68*	0.67*
Pyrethrin II (%)-vs-cinerin I (%)	-0.268	-0.40	-0.27	-0.02	-0.24
Pyrethrin II (%)-vs-cinerin II (%)	0.466	0.47	0.47	0.31	0.43
Pyrethrin II (%)-vs-pyrethrins (%)	0.496	0.84**	0.50	0.81**	0.66*
Jasmolin I (%)-vs-jasmolin II (%)	0.351	0.53	0.35	0.48	0.43
Jasmolin I (%)-vs-cinerin I (%)	-0.411	-0.33	-0.41	-0.36	-0.38
Jasmolin I (%)-vs-cinerin II (%)	-0.605*	0.03	-0.61*	-0.25	-0.36
Jasmolin I (%)-vs-pyrethrins (%)	0.696*	0.70*	0.70*	0.71*	0.70*
Jasmolin II (%)-vs-cinerin I (%)	-0.494	0.01	-0.49	0.04	-0.24
Jasmolin II (%)-vs-cinerin II (%)	0.238	0.29	0.24	0.21	0.24
Jasmolin II (%)-vs-pyrethrins (%)	0.458	0.48	0.46	0.45	0.46
Cinerin I (%)-vs-cinerin II (%)	0.188	-0.29	0.19	0.74**	0.21
Cinerin I (%)-vs-pyrethrins (%)	-0.152	-0.39	-0.15	-0.26	-0.24
Cinerin II (%)-vs-pyrethrins (%)	-0.169	0.29	-0.17	0.00	-0.01

*-*p*<0.05; ***p*<0.01 level of significance, respectively. ENV= year

Table 3: Original genotype by trait data of the nine economic traits of pyrethrum

Genotypes/ Environments	Fresh flower yield/ plot (g)	Dry flower yield / plot (g)	Pyrethrin I (%)	Pyrethrin II (%)	Jasmolin I (%)	Jasmolin II (%)	Cinerin I (%)	Cinerin II (%)	Pyrethrins (%)/HPLC Assy
G1:env1:2014	1264.00	303.35	0.250	0.083	0.008	0.003	0.060	0.023	0.427
G1:env2:2015	2112.00	524.60	0.480	0.145	0.018	0.004	0.003	0.007	0.667
G1:env3:2016	1264.00	303.35	0.250	0.083	0.008	0.003	0.060	0.023	0.427

G1:env4:2017	2112.00	524.60	0.480	0.145	0.018	0.004	0.003	0.007	0.667
G10:env1:2014	1673.00	464.25	0.310	0.131	0.017	0.007	0.004	0.013	0.474
G10:env2:2015	600.00	151.80	0.250	0.060	0.015	0.004	0.005	0.006	0.345
G10:env3:2016	1673.00	464.25	0.310	0.131	0.017	0.007	0.004	0.013	0.474
G10:env4:2017	600.00	151.80	0.250	0.060	0.015	0.004	0.005	0.006	0.345
G11:env1:2014	1360.00	352.40	0.455	0.085	0.018	0.003	0.006	0.006	0.546
G11:env2:2015	1100.50	340.80	0.190	0.028	0.011	0.003	0.005	0.005	0.277
G11:env3:2016	1360.00	352.40	0.455	0.085	0.018	0.003	0.006	0.006	0.546
G11:env4:2017	590.10	150.00	0.085	0.035	0.007	0.002	0.030	0.012	0.171
G2:env1:2014	601.00	147.80	0.080	0.033	0.006	0.002	0.035	0.013	0.169
G2:env2:2015	1557.00	408.60	0.170	0.045	0.006	0.003	0.005	0.007	0.263
G2:env3:2016	601.00	147.80	0.080	0.033	0.006	0.002	0.035	0.013	0.169
G2:env4:2017	1557.00	408.60	0.170	0.045	0.006	0.003	0.005	0.007	0.263
G3:env1:2014	1455.00	266.20	0.310	0.156	0.012	0.006	0.034	0.018	0.536
G3:env2:2015	1708.00	476.20	0.310	0.050	0.012	0.003	0.002	0.003	0.390
G3:env3:2016	1455.00	266.20	0.310	0.156	0.012	0.006	0.034	0.018	0.536
G3:env4:2017	1708.00	476.20	0.310	0.050	0.012	0.003	0.002	0.003	0.390
G4:env1:2014	2098.00	610.50	0.440	0.085	0.018	0.004	0.042	0.009	0.598
G4:env2:2015	474.00	119.50	0.300	0.045	0.014	0.003	0.003	0.004	0.378
G4:env3:2016	2098.00	610.50	0.440	0.085	0.018	0.004	0.042	0.009	0.598
G4:env4:2017	474.00	119.50	0.300	0.045	0.014	0.003	0.003	0.004	0.378
G5:env1:2014	1535.00	376.60	0.275	0.065	0.012	0.003	0.043	0.013	0.411
G5:env2:2015	238.00	50.50	0.310	0.088	0.014	0.003	0.003	0.012	0.512
G5:env3:2016	1535.00	376.60	0.275	0.065	0.012	0.003	0.043	0.013	0.411
G5:env4:2017	238.00	50.50	0.310	0.088	0.014	0.003	0.003	0.012	0.512
G6:env1:2014	1812.00	450.50	0.240	0.200	0.007	0.004	0.020	0.020	0.491
G6:env2:2015	1079.00	355.00	0.270	0.120	0.011	0.004	0.002	0.009	0.438
G6:env3:2016	1812.00	450.50	0.240	0.200	0.007	0.004	0.020	0.020	0.491
G6:env4:2017	1079.00	355.00	0.270	0.120	0.011	0.004	0.002	0.009	0.438
G7:env1:2014	1396.00	358.50	0.390	0.081	0.014	0.004	0.032	0.007	0.578
G7:env2:2015	1173.00	337.80	0.200	0.040	0.010	0.002	0.004	0.005	0.276
G7:env3:2016	1396.00	358.50	0.390	0.081	0.014	0.004	0.032	0.007	0.578
G7:env4:2017	1173.00	337.80	0.200	0.040	0.010	0.002	0.004	0.005	0.276
G8:env1:2014	1160.00	296.50	0.220	0.090	0.011	0.003	0.031	0.011	0.366
G8:env2:2015	1375.00	385.00	0.145	0.050	0.009	0.003	0.002	0.007	0.239
G8:env3:2016	1160.00	296.50	0.220	0.090	0.011	0.003	0.031	0.011	0.366
G8:env4:2017	1375.00	385.00	0.145	0.050	0.009	0.003	0.002	0.007	0.239
G9:env1:2014	1916.00	516.00	0.310	0.090	0.015	0.006	0.004	0.018	0.462
G9:env2:2015	1458.00	517.50	0.200	0.080	0.015	0.005	0.002	0.008	0.338
G9:env3:2016	1916.00	516.00	0.310	0.090	0.015	0.006	0.004	0.018	0.462
G9:env4:2017	1458.00	517.50	0.200	0.080	0.015	0.005	0.002	0.008	0.338
G1:env1:2014	1115.50	300.50	0.230	0.083	0.009	0.003	0.050	0.025	0.408
G1:env2:2015	2200.00	500.00	0.475	0.146	0.016	0.005	0.002	0.006	0.668
G1:env3:2016	1115.50	300.50	0.230	0.083	0.009	0.003	0.050	0.025	0.408
G1:env4:2017	2200.00	500.00	0.475	0.146	0.016	0.005	0.002	0.006	0.668
G10:env1:2014	1700.50	500.25	0.300	0.135	0.016	0.005	0.005	0.012	0.478
G10:env2:2015	675.00	160.80	0.300	0.060	0.012	0.005	0.005	0.006	0.350
G10:env3:2016	1700.50	500.25	0.300	0.135	0.016	0.005	0.005	0.012	0.478
G10:env4:2017	675.00	160.80	0.300	0.060	0.012	0.005	0.005	0.006	0.350
G11:env1:2014	1350.60	350.60	0.450	0.086	0.017	0.002	0.005	0.007	0.546
G11:env2:2015	1250.00	335.40	0.200	0.040	0.012	0.003	0.004	0.006	0.277
G11:env3:2016	1350.60	350.60	0.450	0.086	0.017	0.002	0.005	0.007	0.546
G11:env4:2017	600.20	145.20	0.090	0.033	0.007	0.003	0.032	0.013	0.178
G2:env1:2014	590.10	150.00	0.085	0.035	0.007	0.002	0.030	0.012	0.171
G2:env2:2015	1550.50	450.20	0.185	0.046	0.007	0.002	0.005	0.007	0.265
G2:env3:2016	590.10	150.00	0.085	0.035	0.007	0.002	0.030	0.012	0.171
G2:env4:2017	1550.50	450.20	0.185	0.046	0.007	0.002	0.005	0.007	0.265
G3:env1:2014	1390.50	370.50	0.320	0.160	0.011	0.006	0.031	0.017	0.545
G3:env2:2015	1700.50	480.50	0.309	0.048	0.011	0.002	0.002	0.004	0.391
G3:env3:2016	1390.50	370.50	0.320	0.160	0.011	0.006	0.031	0.017	0.545
G3:env4:2017	1700.50	480.50	0.309	0.048	0.011	0.002	0.002	0.004	0.391
G4:env1:2014	1990.00	670.20	0.450	0.084	0.019	0.005	0.043	0.008	0.607
G4:env2:2015	500.50	150.50	0.280	0.044	0.015	0.002	0.003	0.005	0.380
G4:env3:2016	1990.00	670.20	0.450	0.084	0.019	0.005	0.043	0.008	0.607
G4:env4:2017	500.50	150.50	0.280	0.044	0.015	0.002	0.003	0.005	0.380
G5:env1:2014	1450.00	385.60	0.276	0.065	0.013	0.002	0.042	0.014	0.412
G5:env2:2015	250.35	50.50	0.340	0.090	0.014	0.004	0.002	0.011	0.516
G5:env3:2016	1450.00	385.60	0.276	0.065	0.013	0.002	0.042	0.014	0.412
G5:env4:2017	250.35	50.50	0.340	0.090	0.014	0.004	0.002	0.011	0.516

G6:env1:2014	1812.50	450.50	0.245	0.185	0.007	0.006	0.020	0.024	0.487
G6:env2:2015	1071.78	400.00	0.275	0.120	0.010	0.005	0.003	0.008	0.439
G6:env3:2016	1812.50	450.50	0.245	0.185	0.007	0.006	0.020	0.024	0.487
G6:env4:2017	1071.78	400.00	0.275	0.120	0.010	0.005	0.003	0.008	0.439
G7:env1:2014	1400.00	385.60	0.370	0.080	0.013	0.003	0.033	0.006	0.500
G7:env2:2015	1100.50	340.80	0.190	0.028	0.011	0.003	0.005	0.005	0.277
G7:env3:2016	1400.00	385.60	0.370	0.080	0.013	0.003	0.033	0.006	0.500
G7:env4:2017	1100.50	340.80	0.190	0.028	0.011	0.003	0.005	0.005	0.277
G8:env1:2014	1150.50	300.50	0.225	0.088	0.010	0.004	0.025	0.012	0.364
G8:env2:2015	1370.28	400.00	0.150	0.050	0.009	0.002	0.003	0.008	0.240
G8:env3:2016	1150.50	300.50	0.225	0.088	0.010	0.004	0.025	0.012	0.364
G8:env4:2017	1370.28	400.00	0.150	0.050	0.009	0.002	0.003	0.008	0.240
G9:env1:2014	1800.50	550.00	0.325	0.085	0.015	0.006	0.003	0.017	0.472
G9:env2:2015	1470.50	520.50	0.250	0.080	0.014	0.004	0.003	0.008	0.337
G9:env3:2016	1800.50	550.00	0.325	0.085	0.015	0.006	0.003	0.017	0.472
G9:env4:2017	1470.50	520.50	0.250	0.080	0.014	0.004	0.003	0.008	0.337
G1:env1:2014	1300.00	280.50	0.234	0.085	0.008	0.002	0.050	0.023	0.410
G1:env2:2015	2150.50	550.20	0.470	0.146	0.017	0.004	0.004	0.006	0.669
G1:env3:2016	1300.00	280.50	0.234	0.085	0.008	0.002	0.050	0.023	0.410
G1:env4:2017	2150.50	550.20	0.470	0.146	0.017	0.004	0.004	0.006	0.669
G10:env1:2014	1600.80	480.25	0.300	0.131	0.016	0.006	0.005	0.014	0.479
G10:env2:2015	700.50	155.30	0.300	0.055	0.015	0.005	0.004	0.005	0.390
G10:env3:2016	1600.80	480.25	0.300	0.131	0.016	0.006	0.005	0.014	0.479
G10:env4:2017	700.50	155.30	0.300	0.055	0.015	0.005	0.004	0.005	0.390
G11:env1:2014	1450.50	350.00	0.450	0.085	0.017	0.003	0.005	0.007	0.545
G11:env2:2015	1375.00	385.00	0.145	0.050	0.009	0.003	0.002	0.007	0.239
G11:env3:2016	1450.50	350.00	0.450	0.085	0.017	0.003	0.005	0.007	0.545
G11:env4:2017	1455.00	266.20	0.310	0.156	0.012	0.006	0.034	0.018	0.536
G2:env1:2014	600.20	145.20	0.090	0.033	0.007	0.003	0.032	0.013	0.178
G2:env2:2015	1600.20	410.50	0.180	0.045	0.006	0.003	0.004	0.005	0.265
G2:env3:2016	600.20	145.20	0.090	0.033	0.007	0.003	0.032	0.013	0.178
G2:env4:2017	1600.20	410.50	0.180	0.045	0.006	0.003	0.004	0.005	0.265
G3:env1:2014	1280.50	345.67	0.330	0.167	0.013	0.005	0.031	0.018	0.554
G3:env2:2015	1680.50	500.00	0.308	0.048	0.013	0.003	0.003	0.005	0.392
G3:env3:2016	1280.50	345.67	0.330	0.167	0.013	0.005	0.031	0.018	0.554
G3:env4:2017	1680.50	500.00	0.308	0.048	0.013	0.003	0.003	0.005	0.392
G4:env1:2014	2090.00	600.50	0.450	0.083	0.018	0.005	0.045	0.009	0.610
G4:env2:2015	480.50	145.50	0.285	0.045	0.015	0.002	0.003	0.006	0.390
G4:env3:2016	2090.00	600.50	0.450	0.083	0.018	0.005	0.045	0.009	0.610
G4:env4:2017	480.50	145.50	0.285	0.045	0.015	0.002	0.003	0.006	0.390
G5:env1:2014	1500.00	400.50	0.278	0.066	0.011	0.003	0.041	0.015	0.414
G5:env2:2015	250.00	45.80	0.350	0.089	0.013	0.003	0.003	0.011	0.518
G5:env3:2016	1500.00	400.50	0.278	0.066	0.011	0.003	0.041	0.015	0.414
G5:env4:2017	250.00	45.80	0.350	0.089	0.013	0.003	0.003	0.011	0.518
G6:env1:2014	1550.50	400.60	0.250	0.196	0.008	0.005	0.024	0.023	0.506
G6:env2:2015	1090.00	350.00	0.280	0.119	0.010	0.004	0.003	0.008	0.438
G6:env3:2016	1550.50	400.60	0.250	0.196	0.008	0.005	0.024	0.023	0.506
G6:env4:2017	1090.00	350.00	0.280	0.119	0.010	0.004	0.003	0.008	0.438
G7:env1:2014	1380.50	390.20	0.380	0.080	0.015	0.003	0.034	0.007	0.511
G7:env2:2015	1250.00	335.40	0.200	0.040	0.012	0.003	0.004	0.006	0.277
G7:env3:2016	1380.50	390.20	0.380	0.080	0.015	0.003	0.034	0.007	0.511
G7:env4:2017	1250.00	335.40	0.200	0.040	0.012	0.003	0.004	0.006	0.277
G8:env1:2014	1200.00	300.00	0.225	0.088	0.010	0.005	0.026	0.013	0.367
G8:env2:2015	1400.50	445.50	0.155	0.060	0.008	0.002	0.003	0.007	0.245
G8:env3:2016	1200.00	300.00	0.225	0.088	0.010	0.005	0.026	0.013	0.367
G8:env4:2017	1400.50	445.50	0.155	0.060	0.008	0.002	0.003	0.007	0.245
G9:env1:2014	1980.00	520.50	0.330	0.089	0.017	0.006	0.004	0.018	0.486
G9:env2:2015	1500.00	500.50	0.210	0.089	0.016	0.005	0.003	0.007	0.338
G9:env3:2016	1980.00	520.50	0.330	0.089	0.017	0.006	0.004	0.018	0.486
G9:env4:2017	1500.00	500.50	0.210	0.089	0.016	0.005	0.003	0.007	0.338

ENV= year

Table 4: Mean performance and stable genotype ranking over years of the economics traits in pyrethrum

Fresh flower yield/ plot(g)		**Dry flower yield / plot (g)**		**Pyrethrin I (%)**		**Pyrethrin II (%)**		**Jasmolin I (%)**		**Jasmolin II (%)**		**Cinerin I (%)**		**Cinerin II (%)**		**Pyrethrins (%)/HPLC Assy**	
G	x̄	G	x̄	G	x̄	G	x̄	G	x̄	G	x̄	G	x̄	G	x̄	G	x̄
G1	1690.33	G9	520.83	G4	0.368	G6	0.157	G4	0.017	G10	0.005	G1	0.028	G1	0.015	G1	0.542
G9	1687.50	G1	409.86	G1	0.357	G1	0.115	G9	0.015	G6	0.005	G4	0.023	G6	0.015	G4	0.494
G3	1535.83	G3	406.51	G3	0.315	G3	0.105	G10	0.015	G9	0.005	G5	0.022	G5	0.013	G3	0.468

G6	1402.63	G6	401.10	G11	0.311	G10	0.095	G11	0.014	G1	0.004	G2	0.019	G9	0.013	G6	0.467
G7	1283.33	G4	382.78	G5	0.305	G9	0.086	G1	0.013	G3	0.004	G7	0.019	G3	0.011	G5	0.464
G8	1276.05	G7	358.05	G10	0.293	G5	0.077	G5	0.013	G4	0.004	G3	0.017	G2	0.010	G10	0.419
G4	1272.17	G8	354.58	G7	0.288	G8	0.071	G7	0.013	G11	0.003	G8	0.015	G8	0.010	G11	0.413
G11	1224.42	G10	318.76	G9	0.271	G11	0.071	G3	0.012	G2	0.003	G11	0.012	G10	0.009	G9	0.406
G10	1158.30	G11	310.72	G6	0.260	G4	0.064	G8	0.010	G5	0.003	G6	0.012	G11	0.008	G7	0.403
G2	1083.17	G2	285.38	G8	0.187	G7	0.058	G6	0.009	G7	0.003	G10	0.005	G4	0.007	G8	0.304
G5	870.56	G5	218.25	G2	0.132	G2	0.040	G2	0.007	G8	0.003	G9	0.003	G7	0.006	G2	0.219

G = Genotypes, $\bar{x}$ = Mean over environments; G5 = Check variety CIM Avadh.

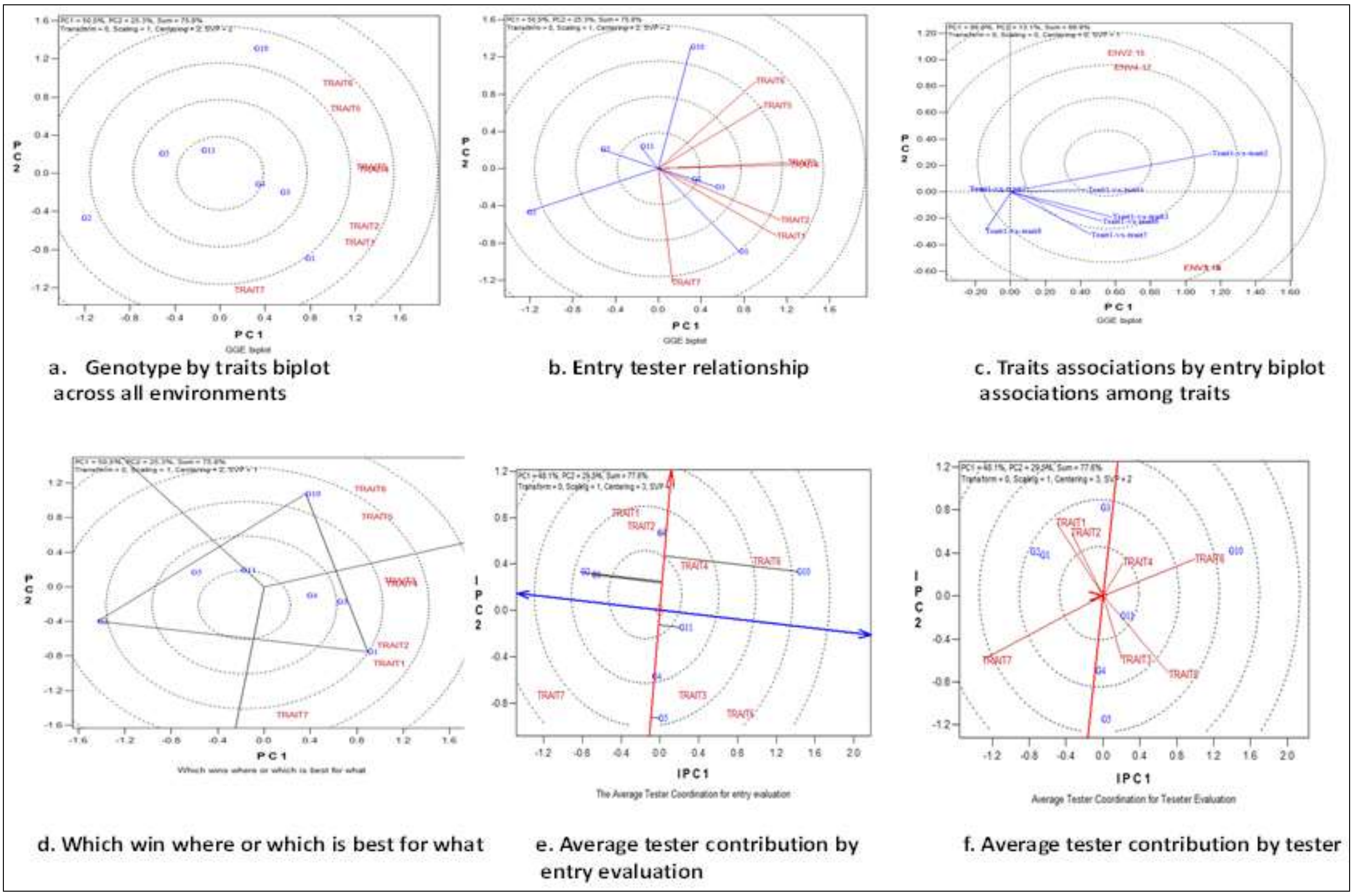

Fig 1 (a. – f.): a. Genotype by traits biplot across all environments; b. entry tester relationship; c. traits associations by entry biplot associations among traits (0.4); d. which win where or which is best for what; e. average tester contribution by entry evaluation; f. average tester contribution by tester evaluation.

Fig 2 (a. – d.): a. Pyrethrum plant of G 1; b. G1 genotype at flowering stage; c. G 9 genotype at flowering stage; d. Field view of G1 genotype.

5. Conclusion

There was crossover G × E interaction for the dry flower yield (g/plot) and pyrethrins content (%) which was lower than the effect of genotypes. The significant G × E interaction for pyrethrins content was also observed in the present study. The traits fresh flower-vs-dry flower yield; pyrethrin I-vs. Jasmolin I; pyrethrin I-vs.-pyrethrins percent were found highly and positively associated (p>0.01%), while, the traits Pyrethrin II-vs-jasmolin II and Jasmolin I-vs-pyrethrins percent found significant and positively associated (p>0.05%) each other across the all four years/environments. Selection of characters will be beneficial according to the behavior of correlations over the selective backgrounds/years. We recommend three genotypes, G9, G1, and G3 g/plot, for the dry flower yield, and G, G4, and G3 for high pyrethrins content as widely adapted and higher-yielding genotypes that could be advanced to the national performance trials for commercialization in India.

6. Acknowledgments

The first author is thankful for the support and facilities provided by Director, CSIR-CIMAP, UP, Lucknow, India. This work was supported by the Council of Scientific and Industrial Research, India, under CSIR-Emeritus Scientist Scheme funding via Sanction No. 21 (1020)/16/EMR-II dated 18-11-2016 under CIMAP Publication No. CIMAP/Pub/2018/38.

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.

7. References

1. Atnaf M, Kidane S, Abadi S, Fisha Z. GGE biplots to analyze soybean multi-environment yield trial data in north Western Ethiopia. Journal of Plant Breeding and Crop Science 2013;5(12):245-254. https://doi.org/10.5897/JPBCS13.0403
2. Bhartiya A, Aditya JP, Kumari V, Kishore N, Purwar JP, Agrawal A. GGE biplot and AMMI analysis of yield stability in multi-environment trial of soybean [*Glycine max* (L.) Merrill] genotypes under rainfed condition of north western Himalayan hills. Journal of Animal and Plant Sciences 2017;27(1):227-238.
3. Gasura E, Setimela P, Souta C. Evaluation of the performance of sorghum genotypes using GGE biplot. Canadian Journal of Plant Science 2015;613:150713053357002. https://doi.org/10.4141/CJPS-2015-119
4. Gurmu F, Mohammed H, Alemaw G. Genotype x environment interactions and stability of soybean for grain yield and nutrition quality. African Crop Science Journal 2009;17(2):87-99.
5. Haque S, Farooqui AHA, Gupta MM, Sangwan RS, Khan A. Effects of ethrel, chlormequat chloride and paclobutrazol on growth and pyrethrins accumulation in *Chrysanthemum cinerariaefolium* Vis. Plant Growth Regul 2007;51:263-269.
6. Hunde D, Malede M, Amogne A, Tefera G. Genotype by environment interaction and yield stability studies on medium maturing soybean genotypes tested in northwest, southern and western parts of Ethiopia for two consecutive years (2016-2017) across five testing locations. Acta Scientific Agriculture 2019;3(9):104-112. https://doi.org/10.31080/ASAG.2019.03.0616.
7. Husain A, Virmani OP, Sharma A, Kumar A, Misra LN. Fennel oil (bitter). Major, essential oil bearing plants of India. Published – Director CIMAP, Lucknow, India 1988;21:103-108.
8. Krisnawati A, Adie MM. Yield stability of soybean promising lines across environments. IOP Conference Series. Earth and Environmental Science 2018, 102(1). https://doi.org/10.1088/1755-1315/102/1/012044
9. Kumar A, Kumar S, Kapoor C. GGE biplot analysis of genotype × environment interaction in soybean grown in NEH regions of India. Environment and Ecology 2014;32(3A):1047-1050.
10. Lal RK, Chandra R, Misra HO, Hari Shankar Lal, Chhote Singth, Krishna AK *et al*. Registration of a new released high yielding variety 'CIMAP Sammohak' of Chamomile (*Chamomile recutita* (L.) Rauschert). Jmaps 2010;12(4):104-106.
11. Lal Raj K, Chanotiya Chandan S, Dhawan Sunita S, Gupta Pankhuri, Mishra Anand, Srivastava Shubham *et al*. Estimation of intra-specific genetic variability and half-sib family selection using AMMI (Additive Main Effects and Multiplicative Interactions) model in menthol mint (*Mentha arvensis* L.). Journal of Medicinal and Aromatic Plant Sciences 2020a;42(1-2):102-113.
12. Lal RK, Chanotiya CS, Gupta Pankhuri. Induced mutation breeding for qualitative and quantitative traits and varietal development in medicinal and aromatic crops at CSIR-CIMAP, Lucknow (India): Past and recent accomplishment. International Journal of Radiation Biology 2020b;96(12):1513-1527. 10.1080/09553002.2020.1834161.
13. Lal RK, Chanotiya CS, Gupta P. Genetic improvement of pyrethrum **(***Tanacetum cinerariifolium* Sch. Bip.**)** through gamma radiation and selection of high yield stable mutants through seven post-radiation generations. International Journal of Radiation Biology 2021;97(3):386-393. DOI: 10.1080/09553002.2021.1864050.
14. Lal RK, Chanotiya CS, Gupta P, Deepa B, Mishra A. Natural essential oils their quality assurance, management and stakes of CSIR-CIMAP (India): Past and future perspective. Journal of Medicinal and Aromatic Plant Sciences 2020c;42(3-4):1-29.
15. Lal Raj Kishori, Chanotiya Chandan Singh, Sing Ved Ram, Dhawan Sunita Singh *et al*. Induced polygenic variations through γ- rays irradiation and selection of novel genotype in chamomile (*Chamomilla recutita* [L.] Rauschert}. International Journal of Radiation Biology 2019;95(9):1242-1250. DOI 10,1080/09553002.2019.1625460.
16. Lal RK, Gupta MM, Verma RK. Genetic variability in Pyrethrum (*Chrysanthemum cinerariefolium*). Book Chapter No.8 in Book-Medicinal Plants Chemistry and properties. Editor Dr (Mrs.) Sampat Nehra. Birla Institute of Scientific Research, Jaipur, Rajasthan (India). Publisher- Avishkar Publishers, Distributors, 807, Vyas Building, Chaura Rasta Jaipur- 302 003 (Rajasthan), India Book Chapter No 2013;8:108-117.
17. Lal RK, Gupta MM, Verma RK, Gupta P, Sarkar S, Singh S. Genetic associations and path analysis of most economic trait in Pyrethrum (*Chrysanthemum*

cinerariefolium). J Herb. Spices. Med. Plants 2014;20(1):92-101. DOI:10.1080/10496475.2013.830280.
18. Mare M, Manjeru P, Ncube B, Sisito G. GGE biplot analysis of genotypes by environment interaction on *Sorghum bicolor L*. (Moench) in Zimbabwe. African Journal of Plant Science 2017;11(7):308-319. https://doi.org/10.5897/AJPS2017.1538
19. Nyombayire A, Derera J, Sibiya J, Ngaboyisonga C. Genotype x environment interaction and stability analysis for grain yield of diallel cross maize hybrids across tropical medium and highland ecologies. Journal of Plant Sciences 2018;6(3):101-106. https://doi.org/10.11648/j.jps.20180603.14.
20. Sarkar S. Importance of diversity and variability. Book Aromatic grasses experience with some *Cymbopogon* species. Pub. Akinik publication169, C-11, Sector-3. Rohini, Delhi India-110086. Book chapter 2021;4:35-50.
21. Singh RK, Chaudhary BD. Variance and covariance analysis. *Biometrical methods in quantitative genetic analysis.* Kalyani Publisher, New Delhi (India) 2014, 57.
22. Singh SP. Genetic divergence over environments in pearl millet (*Pennisetum typhoides*). Genet. Agr 1988;42:35-41.
23. Simion T, Mohammed W, Amsalu B. Genotype by environment interaction and stability analysis of cowpea [*Vigna unguiculata (L.) Walp*] genotypes for yield in Ethiopia. Journal of Plant Breeding and Crop Science 2018;10:249-257. https://doi.org/10.5897/JPBCS2018.0753
24. Sousa MBE, Damasceno-silva KJ, Moura MDE. Genotype by environment interaction in cowpea lines using GGE biplot method 2018;2125:64-71. https://periodicos.ufersa.edu.br/index. http://dx.doi.org/10.1590/1983-21252018v31n108rc.
25. Tukamuhabwa P, Assimwe M, Nabasirye M, Kabayi P, Maphosa M. Genotype-by- environment interaction of advanced generation soybean lines for grain yield in Uganda. African Crop Science Journal 2012;20(2):107-115.
26. Wang IH, Subramanian V, Moorman R, Burlson J, Ko J. Direct determination of pyrethrins in pyrethrum extracts by reverged-phase high performance liquid chromatography with diode-array detection. J. Chromat A 1997;766:277-281.
27. Yan W. Singular-value partitioning in biplot analysis of multi environment trial data. Agronomy 2002;94(5):990-996. https://doi.org/10.2134/agronj2002.0990
28. Yan W, Kang MS. Gge biplot analysis. A graphical tool for breeders, geneticists, and agronomists. Crc Press 2002;1338:224. https://doi.org/10.1201/9781420040371
29. Yan W, Kang MS, Ma B, Woods S, Cornelius PL. GGE biplot vs. AMMI analysis of genotype-by-environment data. Crop Science 2007;47(2):643-655. https://doi.org/10.2135/cropsci2006.06.0374
30. Yan W, Tinker NA. Biplot analysis of multi-environment trial data: Principles and applications. Canadian Journal of Plant Science 2006;86(3):623-645. https://doi.org/10.4141/P05-169.