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ORIGINAL RESEARCH ARTICLE

Stable genotypes selection in Pyrethrum (*Tanacetum Cinerariifolium* Sch. Bip.)

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ABSTRACT

The pyrethrum ***(Tanacetum cinerariifolium Sch. Bip.),*** *which belongs to the Asteraceae family, is a natural source of insecticides that are non-toxic to plants and higher animals. A mutation breeding followed by AMMI analysis was used on the variety Avadh to increase the flowers yield with pyrethrin content (%) and stable genotype selection. Variety Avadh seeds irradiated with gamma rays at 20 to 300 Gy doses. The rigorous exercised M_2-M_7 for the size and synchronous flowering mutants were exercised both within and between families. The four top-ranking mutants, 1(1), 7 (2), 10 (3), and 14 (4), were selected out of the 20 M7 families along with the control var. Avadh was grown for the four consecutive years (2013-14, 2014-15, 2015-16, and 2016-17) in a bench-scale trial (RBD in the three replications plots size = 12 m^2). As a result of high performance, two promising genotypes, namely, 1 and 7, indicated high stability for dry flower yield and pyrethrins content. Therefore, these two stable genotypes may be successfully cultivated in the North Indian plain.*

INTRODUCTION

The genus *Chrysanthemum*, which belongs to the Asteraceae family, is a natural source of insecticides non-toxic to plants and higher animals. The flowers are also in high demand because of their extensive uses in agriculture. The amounts of pyrethrum powder used in insecticides are non-toxic to plants and higher animals; thus, these insecticides are commonly used for edible plants in household and livestock sprays and dust (Singh *et al.*, 1987; Lal *et al.*, 2014; 2020; 2021). The United Republic of Tanzania produced 90% over 6,986 tonnes of the world's pyrethrum. Other countries like Papua New Guinea 1,150 tonnes, Kenya 350 tonnes, and Italy 300 tonnes also produce pyrethrum flowers. Production in Tanzania and Ecuador is also significant (Nagel, 2019). The world's major producing countries are Kenya, Tasmania, and Australia (Lal *et al.*, 2014; 2020; 2021; Freemont *et al.*, 2016; Anonymous, 2020).

In India, the pyrethrum was introduced two centuries ago. Still, this crop couldn't be used significantly in cultivation. Mainly because of asynchronous flowering, blind plants, and low flowers yield and pyrethrins per cent in the flowers,

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along with other factors like fluctuating climatic conditions, market demand, and prizes (Singh *et al.*, 1987; Lal and Sharma, 2002; Lal *et al.*, 2003a, b; Lal *et al.*, 2010; 2014; 2020; 2021). Due to pyrethrins' low biosynthesis in the pyrethrum, there was a broad scope to increase pyrethrins' biosynthesis and the flower yield potential by mutation breeding followed by stability analyses.

For the high pyrethrum production, a pyrethrum breeding program was undertaken at CSIR-CIMAP, Lucknow, India. Since none of the available varieties was strong, a mutation breeding followed by AMMI analysis was used on the variety of Avadh with the objectives: to increase the flowers yield, pyrethrins content (%), and stable genotype selection pyrethrum.

MATERIALS AND METHODS

The dry seeds of the variety Avadh of the pyrethrum (***Tanacetum cinerariifolium* Sch. Bip.**) were irradiated with gamma rays (source cobalt-60) at 20 - 300 Gy doses in the year 2011 during the winter season. They were sown with a variety Avadh at CSIR-CIMAP, Lucknow, within half an hour. The data was collected to select mutants in M_2-M_7 plants based on the different economic traits and plants' vigour (Lal *et al.*, 2020; 2021). After passing separate field evaluation trials, the four top-ranking genotypes, namely 1 (1), 7 (2), 10 (3), and 14 (4), and the control var. Avadh was grown for the four consecutive years (2013-14, 2014-15, 2015-16, and 2016-17) in a bench-scale trial randomized block design in the three replications (plots size = 12 m^2) for the stability analysis and the selection of stable genotypes (s).

The research farm site is 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 four weeding, four irrigations, and fertilizer @ 100 kg N, 60 kg P, and 40 kg K/ha).

Morpho-metric observations

The data was recorded on fresh and dry flower yield (g)/plot and chemical constituents like pyrethrin I, II; jasmolin I, II; cinerin I, II, and pyrethrins content percentage.

Chemical estimation of Pyrethrins

The pyrethrum flowers were plucked and air-dried in the shade. In a soxhlet apparatus, 1 gm of air-dried flowers were used to isolate pyrethrins for 6 hours 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). Pyrethrins' concentration was measured as a mixture of pyrethrin I, II, cinerin I, II, and jasmolin I, II of standard pyrethrin developed as a pyrethrin technical mixture from Sigma-Aldrich, USA, PESTANAL (HPLC assay 21.58%). Sample extracts and standards, protected from heat and light, were placed in a deep freezer at –4° C.

Statistical Analyses

The morphometric data were statistically analyzed by the software CSIR-CIMAP statistics 4.0 ver. available at the institute in the Division of Plant Breeding and Genetic Resources Conservation based on Singh and Chaudhary (1985). Data of the four selected genotypes along with one check var. Avadh of four years was also subjected to AMMI (Additive Main Effects and Multiplicative interactions) model analysis to estimate stability by MATA MODEL VERSION 3.0 software across the year means and stability (Gouch, 2007).

RESULTS AND DISCUSSION

The mutagens are well-identified sources in the medicinal and aromatic crops (Bhagat and Hardas, 1990, Lal and Khanuja, 2003, Jnanesha *et al.*, 2021, Kumar and Lal, 2021, Lal *et al.*, 2006; 1999; 2019; 2020; 2021). In the pyrethrum, the means and ranges have widened significantly for all traits in positive or negative directions in M_2 to M_7 generations (Table 1). The alterations in the qualitative/ quantitative traits like flower yield and pyrethrins content (%) were recorded in pyrethrum genotypes/ mutants. The stability over the years was also confirmed on the four genotypes with the check variety Avadh by the AMMI analysis (Table 2-5; Figures 1-3).

Variations among the genotype/mutants for all nine traits were highly significant ($P < 0.01$).

Variations among the treatments for all nine traits were also highly significant (P < 0.01) except for Jasmolin II (%) traits. Simultaneously, environments (E)/years were significant for fresh, dry flower yield and cinerin I (%) only. Similarly, the genotype × environment interactions were highly significant for the two traits, fresh flowers/plant (g) and pyrethrin I (%) only (Table 1). The principal component analysis (PCA1) was also highly significant (P<0.01) for all nine traits, indicating an ample amount of genetic variability was present in the mutants (Table 1).

In this experiment, four promising mutants with one check var. Avadh of pyrethrum compared using the AMMI model to select high-yielding stable mutants across the years. The rank differences of mutants over the years were indicated strong influences of genotypes × environments/years (g × e) interactions (Table 1). AMMI modal for genotypes × environments/years (g × e) interactions helped the pyrethrum plant breeder quickly select high yielding stable mutants across years. The experiment results indicated that AMMIF and AMMI0 picked the same mutant winner in all four years (100.00%) for all traits as the AMMI index ranked Ist for the mutant 7 for dry flower yield/ plot (g) and total pyrethrins (%) followed by pyrethrin I. Expected values for regression models for the most economic traits in pyrethrum.

Simultaneously, the fresh flower yield /plot (g) and pyrethrin II content (%) followed by jasmolon II and cinerin II ranked Ist for mutant 1 in order. It was observed that the mean performance and AMMI ranking were more authentic over the years. Based on the high AMMI1 values and the four years' mean, the AMMIF/AMMI 1 picked two more stable and high-yielding mutants, namely 7 (2) and 1 (1), instead of other genotypes. These AMMI values are pragmatic for estimating the mean separations and selecting stable high-yielding mutants (Tables 2-5). These findings are also in agreement with several research workers (Dove, 1958; Munro, 1961, Fine, 1963; Rao *et al.*, 1983; Tuikong, 1984; Bhat and Menary, 1986; Bhat and Pandita, 1977; Singh and Sharma, 1989; Lal *et al.*, 2013; 2014; 2015; 2019, 2020; 2021; Lal *et al.*, 2022a; Lal *et al.*, 2022b; Kumar *et al.*, 2022).

The pooled mean performance of the nine economic traits, namely yield of fresh flower/plot (g), dry flower yield/plot (g), and chemical constituents in the dry flower powder: pyrethrin I, II; jasmolin I, II; cinerin I, II, and pyrethrins percentage of the four genotypes and one check variety Avadh of pyrethrum across the four consecutive years ranged from 1361.67-3337.67 /plot (g) for fresh flower yield/plot (g), AMMI0 range (1321.28-3264.95), residual (72.72); 375.00-653.33/ plot (g), AMMI0 range (1321.28-3264.95), residual (72.72); 400.77-652.72 for dry flower yield/plot (g), residual-31.97; 0.23-0.47, AMMI0 range 0.23-0.47, residual (0.020) for pyrethrin I; and 0.36-0.69, AMMI0 range (0.37-0.69), residual (-0.009) for pyrethrins/HPLC assay percentage (Table 2). The scope, count first order, and typical bias values for assessing the significance of mean separations in the data estimates among genotypes over four years in pyrethrum for the different characters are given in the table (3 and 4). The expected values for regression models for the most economic traits of pyrethrum are also presented in table 5.

The rank differences of the genotypes (G) in the different years depicted for all the nine traits, years/environments (E) for the fresh and dry flower yield/plot (g), and genotypes × environments/years (g × e) for the fresh flower yield/plot (g) interactions (Table 1-5). After a critical examination of the table (2-5), some significant facts derived from the results that AMMIF and AMMI0 selected the same winners in all four years (100%) for all nine traits studied (Tables 3 and 4). The sum of squares relationship is calculated as genotypes × environments/years (g × e) degree of freedom times, and error mean sum of the square for the estimation of stability.

The results revealed that the genotypes × environments/years (g × e) sum of squares behaved the different patterns for the nine characters, especially for fresh and dry flower yield/plot (g), and pyrethrins percentage in the dry flower powder of all five genotypes of pyrethrum over four consecutive years. Therefore, considerable selectivity is found mainly in early IPCA and noise, primarily in the late IPCA axis. Thus, such results provide a rough idea for model diagnosis in the early axis for all nine pyrethrum traits (Tables 2-6, Figure 1-3).

The polygenic change due to mutagenesis has been used with effectiveness in the development of

Table 1: Pooled Analysis of variance (ANOVA) of model AMMI1, PCA and linear regressions for the four years of pyrethrum

Sources of variation	Df	Characters (Mean sum of squares)								
		Fresh flowers/ plant (g)	Dry flowers/ plant (g)	Pyrethrin I (%)	Pyrethrin II (%)	Jasmolin I (%)	Jasmolin II (%)	Cinerin I (%)	Cinerin II (%)	Pyrethrins (%)
Treatments	19	1090670.77***	15714.99***	0.0216***	0.00337***	0.00002***	0.000002	0.00042***	0.00006***	0.03400***
Genotypes (g)	4	5127887.17***	69365.94***	0.1012***	0.01598***	0.00007***	0.000005***	0.00200***	0.00030***	0.16129***
Environments (e)	3	45665.02***	4204.15**	0.0003	0.00001	0.000001	0.0000003	0.00001**	0.000001	0.00002
g × e	12	6183.41***	709.05	0.0004**	0.00001	0.000001	0.00000008	0.000003	0.000002	0.00007
Error	40	1116.07	643.35	0.00013	0.00001	0.000001	0.000001	0.000004	0.0000013	0.00012
Total	59	351989.61	5496.93	0.00704	0.00109	0.00001	0.00000102	0.00014	0.00002	0.01103
PCA1	8	2569716.85***	35324.21***	0.0506***	0.00800***	0.00004***	0.000004***	0.001***	0.00015***	0.08065***
PCA2	6	24369.80***	2239.60**	0.0006***	0.00002*	0.000001	0.000001	0.00001**	0.000002	0.00012
PCA3	4	4412.49**	592.80	0.0004**	0.00001	0.000001	0.000001	0.000005	0.000001	0.00002
PCA4	2	570.57	91.80	0.0002***	0.000001	0.000001	0.000001	0.00001**	0.000001	0.00002
Joint Regr	1	32620.13***	689.58	0.000001	0.00001	0.000001	0.000001	0.000001	0.000001	0.000001
Genotype Regres	3	2963.64	270.32	0.00063**	0.00003*	0.0000003	0.000001	0.000001	0.000001	0.000001
Environment Regression	2	6669.22**	2198.69*	0.00010	0.00001	0.000001	0.000001	0.000001	0.000001	0.000005*
Residual	6	3225.24*	435.12	0.00035*	0.00001	0.000001	0.000001	0.000005	0.000005	0.000001

Exceeding by a factor of 1.960, 2.576, or 3.291 are marked with *, **, or *** respectively. Assuming normality, 5%, 1%, and 0.1%; AMMI = Additive main effects and multiplicative interaction; PCA = Principal component analysis

Table 2: Environment/Year wise-mean performance of the mutants with AMMI, index and residual for the four years in the pyrethrum

Geno-type/ Years	Fresh flower yield/plant (g)							Dry flower yield/plant (g)							Pyrethrin I content (%)						
	$\bar{x}$	AMMI 0	Residual	I	$\bar{x}$	I	AMMI 0	$\bar{x}$	AMMI 0	Residual	I	$\bar{x}$	I	AMI 0	$\bar{x}$	AMMI 0	Resid-ual	I	$\bar{x}$	I	AMMI 0
1YearI	**3176.00**	**3157.55**	18.45	1	**3176.00**	**1**	**3157.55**	512.33	526.77	-14.43	2	**620.00**	2	**614.52**	0.31	0.32	-0.015	2	**0.47**	2	**0.46**
2	2082.67	2091.88	-9.217	3	2137.33	3	2160.97	**620.00**	**614.52**	5.48	3	524.67	1	526.77	**0.47**	**0.46**	0.011	3	0.43	3	0.43
3	2137.33	2160.97	-23.63	2	2082.67	2	2091.88	524.67	520.68	3.98	4	513.67	3	520.68	0.43	0.43	-0.003	4	0.35	4	0.35
4	1955.33	1970.05	-14.72	4	1955.33	4	1970.05	513.67	516.27	-2.60	1	512.33	4	516.27	0.35	0.35	-0.007	1	0.31	1	0.32
5	1367.67	1338.55	29.12	5	1367.67	5	1338.55	408.33	400.77	7.57	5	408.33	5	400.77	0.24	0.23	0.014	5	0.24	5	0.23
1 II	**3116.00**	**3140.28**	-24.28	1	**3116.00**	**1**	**3140.28**	550.00	532.97	17.03	2	**633.33**	**2**	**620.77**	0.34	0.33	0.005	2	**0.46**	**2**	**0.47**
2	2081.67	2074.62	7.05	3	2133.33	3	2143.70	**633.33**	**620.72**	12.67	1	550.00	1	532.97	0.46	**0.47**	-0.005	3	0.45	3	0.44
3	2133.33	2143.70	-10.37	2	2081.67	2	2074.62	530.00	526.88	3.12	3	530.00	3	526.88	0.45	0.44	0.013	4	0.35	4	0.36
4	1930.00	1952.78	-22.78	4	1930.00	4	1952.78	521.67	522.47	-0.80	4	521.67	4	522.47	0.35	0.36	-0.009	1	0.34	1	0.33
5	1371.67	1321.28	50.38	5	1371.67	5	1321.28	375.00	406.97	-31.97**	5	375.00	5	406.97	0.23	0.24	-0.004	5	0.23	5	0.24
1YIII	**3124.00**	**3190.88**	-66.88	1	**3124.00**	**1**	**3190.88**	546.67	540.967	5.70	2	**610.00**	**2**	**628.77**	0.34	0.33	0.009	2	**0.47**	**2**	**0.47**
2	2150.00	2125.22	24.783	3	2200.00	3	2194.30	**610.00**	**628.72**	-18.72	1	546.67	1	540.97	**0.47**	**0.47**	0.003	3	0.44	3	0.44
3	2200.00	2194.30	5.70	2	2150.00	2	2125.22	540.00	534.88	5.17	3	540.00	3	534.88	0.44	0.44	-0.003	4	0.36	4	0.36
4	2050.00	2003.38	46.62	4	2050.00	4	2003.38	525.00	530.47	-5.47	4	525.00	4	530.47	0.36	0.36	-0.004	1	0.34	1	0.33
5	1361.67	1371.88	-10.22	5	1361.67	5	1371.88	428.33	414.97	13.37	5	428.33	5	414.97	0.23	0.24	-0.005	5	0.23	5	0.24
1Y IV	**3337.67**	**3264.95**	72.72*	1	**3337.67**	**1**	**3264.95**	556.67	564.97	-8.30	2	**653.33**	2	**652.72**	0.34	0.33	0.001	2	**0.46**	**2**	**0.47**
2	2176.67	2199.28	-22.62	3	2296.67	3	2268.37	**653.33**	**652.72**	0.617	4	563.33	1	564.97	**0.46**	**0.47**	-0.009	3	0.44	3	0.44
3	2296.67	2268.37	28.30	2	2176.67	2	2199.28	546.67	558.88	-12.22	1	556.67	3	558.88	0.44	0.44	-0.007	4	0.38	4	0.36
4	2068.33	2077.45	-9.12	4	2068.33	4	2077.45	563.33	554.47	8.867	3	546.67	4	554.47	0.38	0.36	0.020	1	0.34	1	0.33
	1376.67	1445.95	- 69.28*	5	1376.67	5	1445.95	450.00	438.97	11.03	5	450.00	5	438.97	0.23	0.24	-0.005	5	0.23	5	0.24
Pyrethrin II content (%)								**Jasmolin I content (%)**							**Jasmolin content II (%)**						
1Year I	**0.16**	**0.16**	-0.002	1	**0.16**	**1**	**0.16**	0.01	0.01	-0.0012 *	3	**0.018**	**3**	**0.018**	**0.006**	**0.006**	0.0004	1	**0.006**	**1**	**0.006**
2	0.15	0.15	0.0006	2	0.15	2	0.15	**0.02**	**0.02**	0.0006	2	0.017	2	0.016	0.004	0.004	-0.0001	2	0.004	2	0.004
3	0.09	0.07	0.001	4	0.09	3	0.09	**0.02**	**0.02**	0.0005	4	0.015	4	0.016	0.003	0.004	-0.0004	4	0.004	3	0.004
4	0.09	0.09	0.002	3	0.09	4	0.09	**0.02**	**0.02**	-0.0006	5	0.013	1	0.012	0.004	0.004	0.0003	5	0.004	4	0.004
5	0.08	0.08	-0.002	5	0.08	5	0.08	0.01	0.01	0.0007	1	0.011	5	0.012	0.004	0.004	-0.0003	3	0.003	5	0.004
1Y II	**0.16**	**0.16**	0.002	1	**0.16**	**1**	**0.16**	0.013	0.013	0.0000	3	**0.018**	**3**	**0.018**	**0.005**	**0.005**	-0.0004	1	**0.005**	**1**	**0.005**
2	0.15	0.15	0.001	2	0.15	2	0.15	0.017	0.017	0.0002	2	0.017	2	0.017	0.004	0.004	0.0001	5	0.004	2	0.004
3	0.09	0.09	-0.002	4	0.09	4	0.09	**0.018**	**0.018**	0.0000	4	0.016	4	0.016	0.003	0.004	-0.0002	2	0.004	5	0.004
4	0.09	0.09	-0.002	3	0.09	3	0.09	0.016	0.016	-0.0004	5	0.013	1	0.013	0.004	0.004	0.0002	4	0.004	4	0.004
5	0.08	0.08	0.001	5	0.08	5	0.08	0.013	0.012	0.0003	1	0.013	5	0.012	0.004	0.004	0.0003	3	0.003	3	0.004

1Y III	**0.15**	**0.16**	-0.0029	1	**0.15**	**1**	**0.16**	0.014	0.013	0.0008	3	**0.018**	**3**	**0.018**	**0.005**	**0.005**	-0.0001	1	**0.005**	**1**	**0.005**
2	0.15	0.15	0.0013	2	0.15	2	0.15	0.016	0.017	-0.0007	4	0.017	2	0.017	0.004	0.004	-0.0002	5	0.004	2	0.004
3	0.09	0.09	0.0016	4	0.09	4	0.09	**0.018**	**0.018**	-0.0002	2	0.016	4	0.016	0.004	0.004	0.0001	2	0.004	5	0.004
4	0.09	0.09	0.0004	3	0.09	3	0.09	0.017	0.016	0.0007	1	0.014	1	0.013	0.004	0.004	-0.0001	3	0.004	4	0.004
5	0.08	0.08	-0.0004	5	0.08	5	0.08	0.012	0.013	-0.0006	5	0.012	5	0.013	0.004	0.004	0.0003	4	0.004	3	0.004
1 Y IV	**0.16**	**0.16**	0.0021	1	**0.16**	**1**	**0.16**	0.013	0.013	0.0004	3	0.018	3	0.018	0.006	0.006	0.00002	1	0.006	1	0.004
2	0.15	0.15	-0.0022	2	0.15	2	0.15	0.016	0.016	-0.0001	2	**0.016**	**2**	**0.016**	**0.005**	**0.005**	0.00018	2	**0.005**	**2**	0.004
3	0.09	0.09	-0.0008	4	0.09	4	0.09	**0.018**	**0.018**	-0.0003	4	**0.016**	**4**	**0.016**	0.004	0.004	0.00052	3	0.004	5	0.004
4	0.09	0.09	0.0003	3	0.09	3	0.09	0.016	0.016	0.0003	1	0.013	1	0.013	0.004	0.004	-0.0004	5	0.004	4	0.004
5	0.09	0.08	0.0009	5	0.09	5	0.08	0.012	0.012	-0.0004	5	0.012	5	0.013	0.004	0.004	-0.0003	4	0.004	3	0.004
Cinerin I content (%)								**Cinerin II content (%)**							**Pyrethrins (%)**						
1 Y I	0.03	0.03	-0.001	4	**0.05**	**4**	**0.05**	**0.018**	**0.018**	-0.0003	4	**0.018**	**1**	**0.018**	0.54	0.54	-0.001	2	**0.69**	**2**	**0.69**
2	0.02	0.02	0.0002	3	0.04	3	0.04	0.008	0.008	0.0002	1	**0.018**	**4**	**0.018**	**0.69**	**0.69**	-0.001	3	0.59	3	0.59
3	0.04	0.04	0-0000	1	0.03	1	0.03	0.008	0.008	-0.0002	5	0.012	5	0.012	0.59	0.59	0.001	4	0.55	4	0.54
4	**0.05**	**0.05**	-0.0004	5	0.03	5	0.02	**0.018**	**0.018**	0.0002	3	0.008	3	0.008	0.55	0.54	0.005	1	0.54	1	0.54
5	0.03	0.02	0.0013	2	0.02	2	0.02	0.012	0.012	0.0002	2	0.008	2	0.008	0.36	0.37	-0.003	5	0.36	5	0.37
1 Y I1	0.03	0.03	-0.0004	4	**0.05**	**4**	**0.05**	**0.018**	**0.018**	0.0004	1	**0.018**	**1**	**0.018**	0.54	0.54	-0.001	2	**0.69**	**2**	**0.69**
2	0.02	0.02	0.0009	3	0.04	3	0.04	0.007	0.007	-0.0005	4	0.017	4	0.017	**0.69**	**0.69**	-0.004	3	0.59	3	0.59
3	0.04	0.04	-0.0006	1	0.03	1	0.03	0.009	0.008	0.0008	5	0.011	5	0.011	0.59	0.59	0.001	4	0.55	4	0.55
4	**0.05**	**0.05**	0.0013	5	0.02	5	0.03	0.017	0.017	-0.0005	3	0.009	3	0.008	0.55	0.55	0.003	1	0.54	1	0.54
5	0.02	0.03	-0.0013	2	0.02	2	0.02	0.011	0.011	-0.0002	2	0.007	2	0.007	0.37	0.37	0.001	4	0.37	5	0.37
1 Y III	0.04	0.03	0.0014	4	**0.05**	**4**	**0.05**	**0.019**	**0.018**	0.0007	1	**0.019**	**1**	**0.018**	0.54	0.54	-0.003	2	**0.69**	**2**	**0.69**
2	0.02	0.02	-0.0007	3	0.04	3	0.04	0.008	0.008	-0.0002	4	**0.019**	**4**	**0.018**	**0.69**	**0.69**	0.001	3	0.59	3	0.59
3	0.04	0.04	-0.0002	1	0.04	1	0.03	0.007	0.008	-0.0009	5	0.011	5	0.012	0.59	0.59	0.002	4	0.55	4	0.55
4	**0.05**	**0.05**	0.00005	5	0.03	5	0.03	**0.019**	**0.018**	0.0009	2	0.008	3	0.008	0.55	0.55	0.001	1	0.54	1	0.54
5	0.03	0.03	-0.0005	2	0.02	2	0.02	0.011	0.012	-0.0005	3	0.007	2	0.008	0.37	0.37	-0.002	5	0.37	5	0.37
1 Y IV	0.04	0.04	0.0001	4	**0.05**	**4**	**0.05**	**0.017**	**0.018**	-0.0007	1	**0.017**	**1**	**0.018**	0.55	0.54	0.006	2	**0.69**	**2**	**0.69**
2	0.02	0.02	-0.0004	3	**0.05**	**3**	**0.05**	0.008	0.008	0.0005	4	**0.017**	**4**	**0.018**	**0.69**	**0.69**	0.004	3	0.58	3	0.59
3	**0.05**	**0.05**	0.0008	1	0.04	1	0.04	0.009	0.008	0.0004	5	0.012	5	0.012	0.58	0.59	-0.005	1	0.55	4	0.55
4	**0.05**	**0.05**	-0.0010	5	0.03	5	0.07	**0.017**	**0.018**	-0.0006	3	0.009	3	0.008	0.54	0.55	-0.009 *	4	0.54	1	0.54
5	0.03	0.03	0.0005	2	0.02	2	0.02	0.012	0.012	0.0005	2	0.008	2	0.008	0.37	0.37	0.004	5	0.37	5	0.37

*P<0.05, **P<0.01; Y=Year; x?=Mean data; I=Index/mutants. Genotype 1 (1), 7(2), 10 (3) ,4 (14), 5 (Var. Avadh,/Check); AMMI = additive main effects and multiplicative interaction: AMMI 0 = the predicted value when no multiplicative terms are used

Table 3: Scope, count first order and typical bias values in the different characters in the genotypes of pyrethrum

S. No.	Characters	Scope	Count	First-order	Typical bias
1.	Fresh flower yield/plot (g)	Genotypes within one environment/years	5	1.16	22.4311
		Environments/years within genotypes	4	1.03	19.8545
		All treatments	20	1.87	36.0196
2.	Dry flower yield/plot (g)	Genotypes within one year	5	1.16	17.0305
		Year within genotypes	4	1.03	15.0743
		All treatments	20	1.87	27.3475
3.	Pyrethrin I (%)	Genotypes within one year	5	1.16	0.0077
		Year within genotypes	4	1.03	0.0068
		All treatments	20	1.87	0.0123
4.	Pyrethrin II (%)	Genotypes within one year	5	1.16	0.0020
		Year within genotypes	4	1.03	0.0018
		All treatments	20	1.87	0.0032
5.	Jasmolin I (%)	Genotypes within one year	5	1.16	0.0010
		Year within genotypes	4	1.03	0.0009
		All treatments	20	1.87	0.0017
6.	Jasmolin II (%)	Genotypes within one year	5	1.16	0.0006
		Year within genotypes	4	1.03	0.0006
		All treatments	20	1.87	0.0010
7.	Cinerin I (%)	within genotypes one year	5	1.16	0.0014
		Year within genotypes	4	1.03	0.0012
		All treatments	20	1.87	0.0022
8.	Cinerin II (%)	Genotypes within one year	5	1.16	0.0008
		Year within genotypes	4	1.03	0.0007
		All treatments	20	1.87	0.0013
9.	Pyrethrins (%)	Genotypes within one year	5	1.16	0.0075
		Year within genotypes	4	1.03	0.0067
		All treatments	20	1.87	0.0120

Table 4: Values for assessing the significance of mean separations in the data estimates among genotypes over four years in pyrethrum

S. No.	Estimates	Data estimates % of GM								
		Fresh flower yield/plot (g)	Dry flower yield/plot (g)	Pyrethrin I (%)	Pyrethrin II (%)	Jasmolin I (%)	Jasmolin II (%)	Cinerin I (%)	Cinerin II (%)	Pyrethrins (%)
1.	Unweighted GM without imputed data	2174.67	530.45	0.366	0.113	0.015	0.0043	0.036	0.0127	0.547
2.	Root error mean square with 40 df	33.41	25.36	0.011	0.003	0.002	0.0009	0.002	0.0012	0.011
3.	S.E. treatment means with three reps.	19.29	14.64	0.007	0.002	0.001	0.0005	0.001	0.0007	0.006
4.	C.V of treatment means %	0.89	2.76	1.802	1.512	5.902	12.5705	3.271	5.3285	1.174
5.	SED between two treatments means	27.28	20.71	0.009	0.002	0.001	0.0008	0.002	0.0010	0.009
6.	With 40 df $t_{(.05)}$ of 2.02 giving $LSD_{(.05)}$	55.1	41.86	0.019	0.005	0.003	0.0016	0.003	0.0019	0.018

GM=grand mean; C.V.=Coefficient of variation; S.E.=Standard error; SED-Standard error of difference.

Table 5: Expected Values for Regression Models for the most economic traits in pyrethrum

Environments /Years	Geno-types	Genetic parameters								
		Dry flower yield/plot (g)				Pyrethrin (%)				
		Additive	Joint Regr	GEN Regrs	ENV Regrs	Additive	Joint Regr	GEN Regrs	ENV Regrs	Both Regrs
1	1	526.77	527.32	529.05	526.54	0.54185	0.54181	0.54041	0.54182	0.54042
1	2	614.52	619.49	617.4	612.5136	0.68743	0.68914	0.68769	0.68868	0.68723
1	3	520.68	520.93	527.21	520.5843	0.58585	0.58634	0.58683	0.58621	0.5867
1	4	516.27	516.29	511.80	516.2572	0.54385	0.54383	0.54723	0.54384	0.54724
1	5	400.77	394.97	393.57	403.1008	0.36668	0.36455	0.36351	0.36512	0.36407
2	1	532.97	533.29	534.28	535.3971	0.54472	0.54475	0.54578	0.54475	0.54578
2	2	620.72	623.59	622.36	642.5945	0.6903	0.68904	0.69011	0.68886	0.68993
2	3	526.88	527.03	530.65	527.9656	0.58872	0.58836	0.58799	0.5883	0.58794
2	4	522.47	522.48	519.89	522.5701	0.54672	0.54673	0.54422	0.54673	0.54422
2	5	406.97	403.62	402.82	381.4727	0.36955	0.37112	0.37189	0.37136	0.37213
3	1	540.97	540.98	541.04	539.4013	0.54338	0.54338	0.54328	0.54335	0.54325
3	2	628.72	628.87	628.80	614.6264	0.68897	0.68909	0.68898	0.69039	0.69029
3	3	534.88	534.89	535.08	534.1863	0.58738	0.58742	0.58745	0.58779	0.58783
3	4	530.47	530.47	530.33	530.4001	0.54538	0.54538	0.54562	0.54537	0.54561
3	5	414.97	414.79	414.75	431.3859	0.36822	0.36807	0.36799	0.36643	0.36635
4	1	564.97	564.08	561.31	564.3241	0.54405	0.54406	0.54453	0.54408	0.54454
4	2	652.72	644.72	648.12	646.9322	0.68963	0.68907	0.68955	0.6884	0.68888
4	3	558.88	558.49	548.39	558.5972	0.58805	0.58789	0.58772	0.5877	0.58753
4	4	554.47	554.43	561.64	554.4393	0.54605	0.54606	0.54492	0.54606	0.54493
4	5	438.97	448.28	450.54	445.7072	0.36888	0.3696	0.36994	0.37043	0.37078

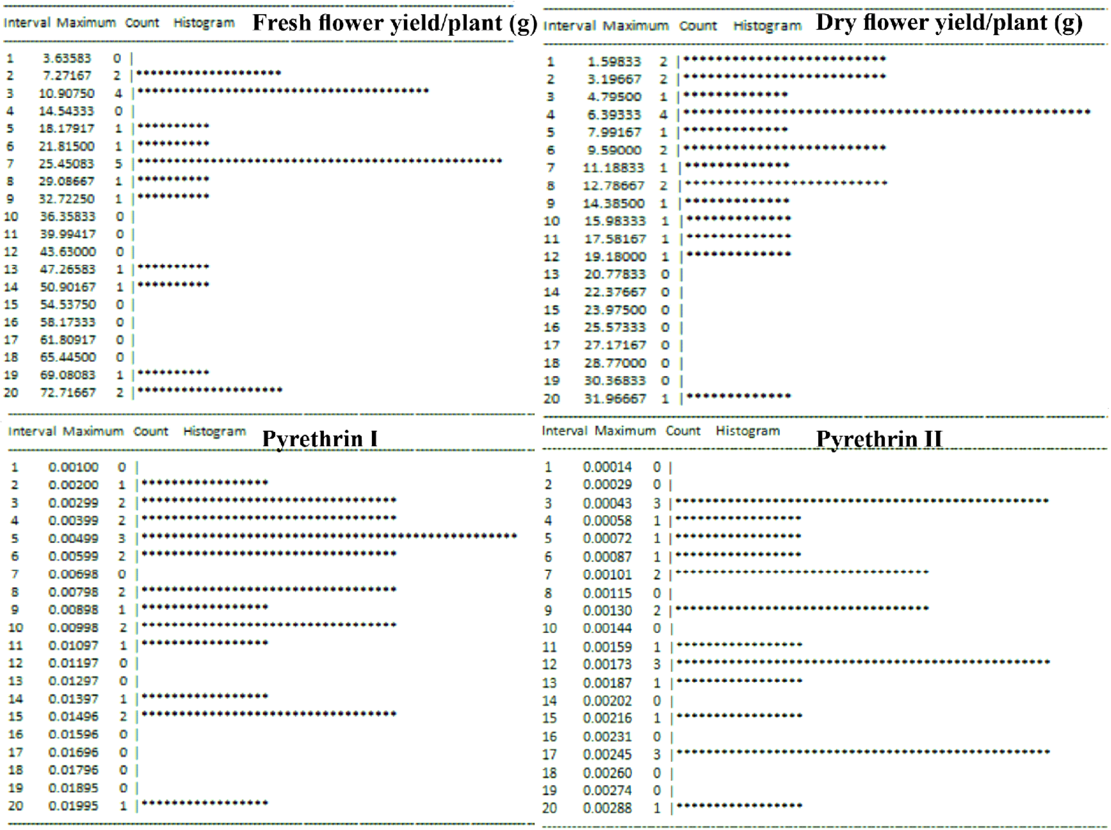

Figure 1:A histogram for the AMMI0 residuals of characters fresh, dry flower yield /plot (g) and pyrethrin I and II of pyrethrum

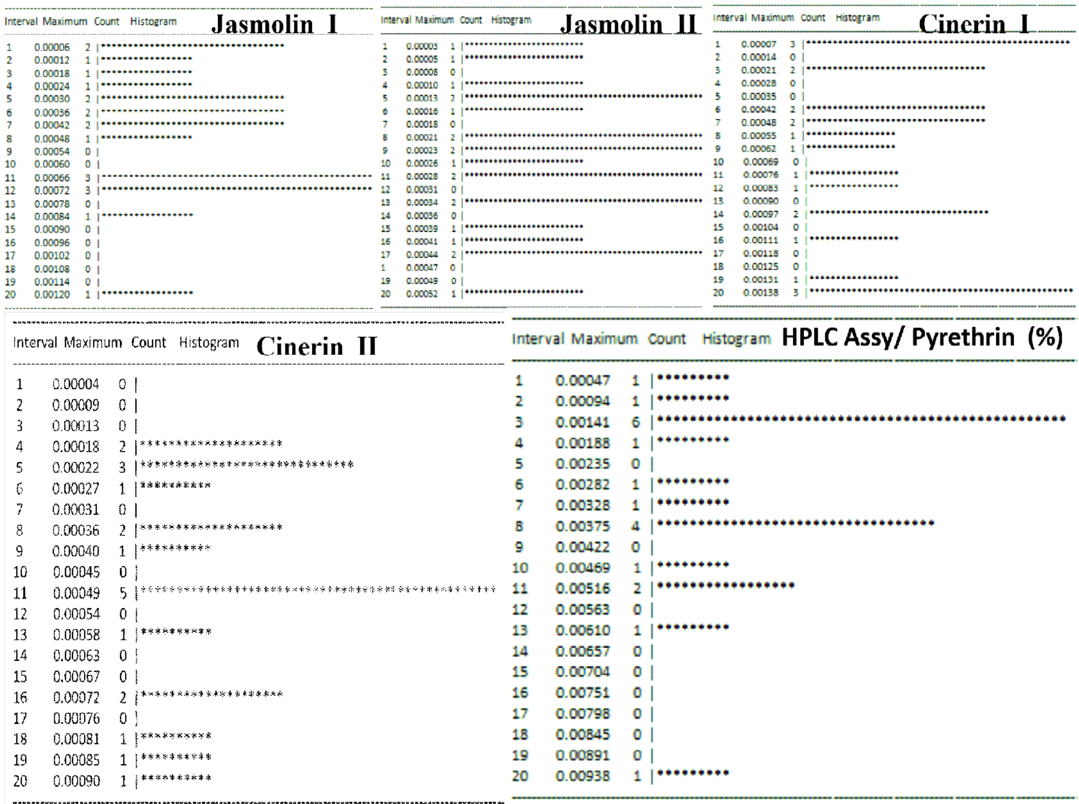

Figure 2: A histogram for the AMMI0 residuals of characters jasmolin, cinerin I, II, and pyrethrin % in the pyrethrum

Figure 3: High flower and pyrethrins yielding stable genotypes 1(left) and 7 (right)

medicinal and aromatic varieties (Lal *et al*., 1999; Lal and Khanuja, 2003; Sharma *et al*., 2004; Lal *et al*., 2004; 2006; Lal and Khanuja, 2007, Lal *et al*., 2010; 2019; 2020; 2021). The changes in means and variances of yield traits with stability over the years could be utilized to select promising high yield stable genotypes of pyrethrum. As an outcome of high mutagenic efficiency and regress screening for stability over the years in the multi-year stability field trials, the two stable genotypes, namely 1(1) and 7(2), were identified. These well stable genotypes are recommended for cultivation in the north Indian plain.

CONCLUSION

In a nutshell, significant variations were found for flower yield, pyrethrins contents, and component traits. As a result of stability analysis, two promising genotypes of pyrethrum, namely, mutants 1(1) and 7(2), indicated high stability for dry flower yield and pyrethrins content. Therefore, these two stable mutants can be exploited for cultivation in the North Indian plain.

ABBREVIATIONS

AMMI = additive main effects and multiplicative interaction; AMMI0 = the predicted value when no multiplicative terms are used; AMMIF = *AMMI* model via *F*-tests; ASV = AMMI stability value; ENV = environment; GEN = genotype; GEI = genotype × environment interaction; G×E or g×e = genotypes×environments/years; Gy = gray is the international system of units (SI) equivalent of 100 rads; GSI = genotype selection index; IPCA = interaction principal component axis; PCA = principal component analysis; ResAMMI = residual estimated by the AMMI model; RCBD = randomized complete block design

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