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Research Article

Stability analysis for yield attributing traits and total alkaloid content in ashwagandha (*Withania somnifera* L.)

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Abstract
An experiment to study stability of Ashwagandha genotypes was conducted during *Kharif* 2018-19 at three different environments. High influence of environment was observed as G x E was significant for all the studied traits. Based upon stability parameters, the genotypes JA-20, UWS-305, UWS-309 and UWS-314 were identified as stable for above average environment, whereas JA-134 was found stable under below average environment for root yield at harvest. UWS-305 showed below average stability for total alkaloid content. Out of the 45 crosses, above average stability was depicted by UWS-305 x UWS-10 and UWS-304 x RVA-100 while below average stability was showed by UWS-309 x RVA-100 for root yield at harvest along with total alkaloid content. Hence, above identified stable genotypes may be beneficial in breeding programme for improvement of root yield and alkaloid content in ashwagandha.

Keywords: Ashwagandha, G x E interaction, Root yield, Total alkaloid content

INTRODUCTION

Herbal plants with medicinal properties have world-wide importance and the global market is around $6.2 billion, which will touch to $5 trillion by the year 2050 (Ahmed *et al.,* 2022; Kumar *et al.,* 2020[a]). Ashwagandha (*Withania somnifera* L.) a type of herbal plant, commonly known as "Winter-cherry" which contains chromosome number 2n=48 (Mozaffarian, 2003). It is primarily an autogamous and self-compatible crop and belongs to Solanaceae family (Mir *et al.,* 2012). The worldwide interest of Ashwagandha and popularity for its roots give adequate opportunity to develop this plant at business scale furthermore, the cost of roots is also alluring (Shinde *et al.,* 2014). It contains highly effective anti-oxidants *viz.,* glutathione peroxides and superoxide dismutase, which have beneficial effects on human body, such as anti-swelling, anti-strain as well as wrinkle-free skin. Furthermore, the alkaloid ingredients of ashwagandha are not only used in Ayurveda but also in Unani medicinal formulations due to their curative effect specially in hiccups, dropsy, rheumatism, bronchitis, stomach pain, lung inflammation, various female disorders and skin diseases (Kumar *et al.,* 2011).

Ashwagandha gives gainful monetarily return in contrast with traditional crops due to its medicinal properties. However, it remains largely as an underutilized and less exploited crop in terms of genetic and breeding point of view. So, crop improvement strategies should be formulated to get desirable results, as we know that a cultivar to be successful at commercial level, must perform well across the wide range of environments. The quantitative trait such as yield is highly influenced by the environment and any deviation from the consistent performance of a genotype over the environments is termed as genotype x environment interaction (Dwivedi *et al.,* 2020; Philanim *et al.,* 2022). In Ashwagandha, total alkaloid content is of the ultimate economic importance which is greatly influenced by environmental conditions (Li *et al.,* 2018; Munaro *et al.,* 2011), therefore, the stability analysis should be carried out to access reliable performance of promising new varieties/ hybrids over the environments. Hence in ashwagandha, an experiment was conducted on genotype x environmental interaction by adopting the model suggested by Eberhart and Russell (1966).

MATERIALS AND METHODS

The present investigation was carried out during *Kharif* season of 2018-19, at three different locations/ environments of Southern region of Rajasthan *viz.,* Instructional Field, Rajasthan College of Agriculture- Udaipur (E_1), Krishi Vigyan Kendra- Chittorgarh (E_2) and Agriculture Research Sub-Station- Vallabhnagar (E_3) and at each location, the trial was laid out in three replications. The experimental material comprised of 15 lines (collected from Medicinal Plant Unit, MPUAT, Udaipur) *viz.,* UWS-301 (L_1), UWS-302 (L_2), UWS-303 (L_3), UWS-304 (L_4), UWS-305 (L_5), UWS-306 (L_6), UWS-307 (L_7), UWS-308 (L_8), UWS-309 (L_9), UWS-310 (L_{10}), UWS-311 (L_{11}), UWS-312 (L_{12}), UWS-313 (L_{13}), UWS-314 (L_{14}) and UWS-315 (L_{15}); 3 testers *viz.,* UWS-10 (T_1), WS-90-146 (T_2), RVA-100 (T_3), (both T_1 and T_2 testers from AICRP-M&AP, Udaipur and T_3 from JNKVV, Jabalpur) and their 45 F_1s along with 2 checks (JA-134 and JA-20, both from JNKVV, Jabalpur). The 45 F_1s experimental hybrids were produced through hybridization including 15 lines (females) along with 3 testers (males) in line × tester mating design (Kempthorne, 1957) during *Kharif* season of 2017-18. Observations were recorded on following characters *viz.,* days to 75 per cent maturity (on plot basis), while for other remaining traits on plant basis by using 10 randomly selected plants i.e. number of secondary branches/ plant, number of berries/ plant, number of secondary and tertiary roots/ plant, root yield at harvest, dry matter content of root, test weight of seed and total alkaloid content (Misra, 1996). The pooled data of all the three environments of above characters were subjected to statistical analysis for stability as per model suggested by Eberhart and Russell (1966).

RESULTS AND DISCUSSION

Analysis of variance based upon phenotypic stability (**Table 1**) indicated that the mean squares due to genotypes along with environment + (genotypes x environments) and G x E (linear) were found highly significant for all characters under study. The genotypes or treatments differed considerably with respect to their stability and prediction for these traits would be difficult because mean squares due to pooled deviation were significant, which suggested that linear and non-linear components played an important role in total G x E interactions for these characters. The character wise parameters of stability are presented in **Table 2.**

Stability parameter for days to 75 per cent maturity indicated that six parents *viz*., T_2, T_3, L_4, L_6, L_7, L_{15} and one check (JA-134) along with five hybrids *viz*., L_7 x T_1, L_9 x T_1, L_7 x T_2, L_4 x T_3, L_8 x T_3 were stable under above average environment, while one parent T_1 and nine hybrids *viz*., L_2 x T_1, L_4 x T_1, L_{10} x T_1, L_{11} x T_1, L_{13} x T_1, L_{15} x T_1, L_{13} x T_2, L_{12} x T_3, L_{13} x T_3 were identified to be stable under below average environment, whereas, the only parent L_{12}, was identified as well adapted and stable across the environments. In case of number of secondary branches per plant, none of the hybrid, but only one parent i.e. T_3 was found stable across the environments, while for higher number of berries per plant only one cross i.e. L_5 x T_1 was found suitable with average stability over the environments. In terms of the trait i.e. secondary and tertiary roots per plant, the genotypes i.e. T_3, JA-20 and five hybrids *viz.,* L_2 x T_1, L_5 x T_1, L_9 x T_1, L_7 x T_2, L_1 x T_3 exhibited non-significant deviation from regression (S^2d) and regression coefficient less than unity (b <1) with higher mean over the population mean. Therefore these genotypes were considered suitable and stable in above

Table 1. ANOVA for stability for different characters in ashwagandha (Eberhart and Russel, 1966 Model)

S.No.	Characters	Genotypes	E+(G x E)	E (L)	G x E (L)	Pooled deviation	Pooled error
		[64]	[130]	[1]	[64]	[65]	[384]
1	Days to 75 per cent maturity	135.71**	107.35**	1.03	136.28**	80.49**	17.72
2	Number of secondary branches per plant	9.81**	0.21**	0.00	0.25**	0.17**	0.04
3	Number of berries per plant	3329.41**	177.72**	1.34	195.10**	163.32**	35.84
4	Number of secondary and tertiary roots per plant	1.27**	0.09**	0.00	0.10**	0.09**	0.02
5	Root yield at harvest	26.87**	2.41**	0.02	3.13**	1.73**	0.35
6	Dry matter content of root	42.94**	11.93**	0.01	12.19**	11.87**	1.21
7	Test weight of seed	0.07**	0.01**	0.00	0.01**	0.02**	0.00
8	Total alkaloid content	0.01**	0.00**	0.00	0.00**	0.00**	0.00

*, ** Significant at 5% and 1%, respectively

Table 2. Stability parameters for different characters in Ashwagandha

S.No.	Genotype	Days to 75 per cent maturity			Number of secondary branches per plant			Number of berries per plant			Number of secondary and tertiary roots per plant		
		μ	b	S^2d	μ	b	S^2d	μ	B	S^2d	μ	b	S^2d
1	T_1	168.21	1.49	-12.053	7.66	-3.58	0.064	91.99	-0.86+	-35.242	4.77	1.07	0.070*
2	T_2	176.58	0.30	-10.470	9.02	-0.80+	-0.036	143.41	1.23	-5.156	4.94	0.49	0.083*
3	T_3	181.00	0.88	22.924	13.12	1.05	-0.025	181.44	1.71	-32.796	4.38	-1.08	0.053
4	L_1	188.77	1.45	-14.073	8.73	2.28	0.066	117.29	1.49**++	-35.834	3.56	-0.24	0.279**
5	L_2	185.97	0.76	12.319	6.22	2.96	0.447**	81.27	1.13	-33.451	3.12	1.75	0.196**
6	L_3	173.95	1.11	107.561**	6.76	1.92	-0.003	80.95	1.54	-29.962	2.45	2.10	0.167**
7	L_4	178.28	0.36	13.451	5.87	1.45	0.004	72.84	-0.70	12.781	3.22	2.49	0.190**
8	L_5	189.14	-0.23	134.782**	11.27	4.21	2.024**	165.72	0.87	-34.581	4.56	3.79	0.286**
9	L_6	179.59	0.83	-13.217	5.57	1.77	0.678**	73.40	1.80	-24.895	3.19	3.07	0.127**
10	L_7	177.65	0.46	36.281	6.69	1.99	-0.000	77.77	0.43	-10.842	4.33	-0.77	0.083*
11	L_8	192.55	1.43	1.166	8.45	-0.12	0.116*	95.78	0.38	120.687*	5.25	-0.82	0.075*
12	L_9	193.91	1.31	70.420*	12.62	1.40	0.293**	163.54	-0.77	-5.276	5.92	3.67	0.030
13	L_{10}	183.56	0.80	18.874	6.77	1.53	-0.035	78.57	1.28	114.798*	3.66	-2.01	0.092*
14	L_{11}	184.18	0.85	19.797	5.83	1.61	0.104*	75.71	-0.62	3.813	3.21	0.93	0.069*
15	L_{12}	180.93	0.98*	-17.381	7.38	0.49	0.608**	82.99	0.46	-29.408	2.15	2.58	-0.004
16	L_{13}	192.45	1.48	122.559**	6.23	-2.66	0.219**	73.07	2.29	66.912	4.34	-1.44	0.200**
17	L_{14}	191.84	0.27	76.127*	12.69	-0.46	1.295**	171.77	-0.65	33.222	4.24	-1.39	0.120**
18	L_{15}	180.68	0.81*	-17.668	10.42	5.01*+	-0.036	130.40	0.61	250.490**	2.96	0.77	0.193**
19	L_1 x T_1	184.42	2.02	104.535**	9.19	4.03	0.043	96.95	0.46	184.870*	3.58	2.14	0.043
20	L_2 x T_1	183.54	1.97	-3.999	8.45	1.28*	-0.036	89.42	-2.20	36.348	3.74	-3.78	0.027
21	L_3 x T_1	185.36	0.17	155.021**	9.20	-0.22	-0.033	107.04	-0.22	131.348*	3.02	3.90	0.035
22	L_4 x T_1	177.61	1.38	-3.971	8.13	0.77	0.046	75.99	1.04	-26.400	2.95	3.49	0.032
23	L_5 x T_1	189.84	-0.21	118.874**	11.00	0.32	0.052	151.27	1.02	75.901	3.58	-1.70	-0.004
24	L_6 x T_1	173.68	1.21	120.609**	7.82	0.03	-0.017	76.67	0.79	-31.687	2.85	2.84	-0.015
25	L_7 x T_1	182.99	0.53	48.209	8.85	-1.65	-0.025	84.49	0.64	199.667*	2.89	1.14	-0.017
26	L_8 x T_1	192.04	1.59	120.618**	8.73	2.17	0.059	89.83	-0.85	342.158**	3.94	2.66**+	-0.020
27	L_9 x T_1	173.17	0.93	27.781	11.93	1.74*	-0.036	148.82	2.38	-16.272	3.64	-1.58+	-0.020
28	L_{10} x T_1	175.28	2.58*	-16.421	8.66	2.51	0.043	75.03	2.44	351.854**	2.66	3.63	-0.018
29	L_{11} x T_1	179.77	2.24**+	-17.671	8.34	0.52	0.005	78.43	0.69	168.626*	3.20	-0.34	0.299**
30	L_{12} x T_1	172.42	1.04	237.951**	8.92	-0.39	-0.025	111.73	1.04	158.750*	3.44	2.90	-0.015
31	L_{13} x T_1	180.58	2.49	3.053	7.91	-0.63	-0.028	82.83	-0.59	207.389**	2.94	0.32	-0.012
32	L_{14} x T_1	184.32	-0.96	-14.219	11.34	1.34	0.327**	143.67	2.19	84.174	3.21	1.39	-0.006
33	L_{15} x T_1	179.55	2.77	16.446	8.13	-5.01	0.063	95.81	1.14	-21.282	3.88	4.75	-0.003
34	L_1 x T_2	195.53	1.71	77.366*	9.51	-0.27	0.078	116.79	1.29	393.640**	3.51	-3.47	-0.014
35	L_2 x T_2	194.82	1.60	-3.742	9.16	-1.27	0.207*	103.11	2.31*	-32.982	2.94	-3.09	0.040
36	L_3 x T_2	183.08	0.60	201.180**	9.13	1.00	0.201*	89.42	1.13	374.227**	3.05	1.67*	-0.020
37	L_4 x T_2	174.87	0.79	85.339*	9.81	-0.51	0.060	105.77	0.77	2.440	3.01	-0.48	0.002
38	L_5 x T_2	194.08	0.15	-2.246	12.21	0.74	-0.026	139.37	1.00	156.707*	3.76	1.75	0.003
39	L_6 x T_2	177.70	0.59	202.761**	9.08	0.84	0.087	96.03	-0.44	99.150*	3.54	2.44	0.257**
40	L_7 x T_2	174.42	-1.32**++	-17.716	9.11	-0.18	0.095	88.31	1.94	-12.228	3.56	0.58	0.000
41	L_8 x T_2	188.17	1.78	-15.210	10.28	4.45	0.182*	113.37	1.40	643.583**	3.32	1.37	0.083*
42	L_9 x T_2	188.90	1.38	228.504**	10.74	-1.65	-0.007	151.14	2.74**+	-35.754	3.67	2.57	-0.006
43	L_{10} x T_2	195.14	0.68	60.680*	8.73	-1.28	0.102*	89.70	0.75	295.444**	3.01	-4.41	0.538**
44	L_{11} x T_2	180.98	3.10	57.933*	8.86	-0.86	0.032	86.44	1.28	154.912*	2.98	1.06	0.011
45	L_{12} x T_2	182.59	1.55	452.818**	9.03	0.85	-0.027	114.13	0.72	380.788**	2.78	2.01	0.016
46	L_{13} x T_2	174.18	1.67	-17.718	8.83	-0.25	0.347**	93.94	3.06*+	-35.620	3.59	-1.47	0.083*
47	L_{14} x T_2	188.60	-1.62	259.047**	12.95	0.62	-0.036	175.17	1.64	-30.168	3.07	-0.10	-0.015
48	L_{15} x T_2	181.33	1.43	347.736**	11.73	4.00*+	-0.037	130.16	2.52	143.876*	3.65	2.08	0.037
49	L_1 x T_3	186.46	1.85	-10.083	10.68	1.30	0.168*	143.00	2.20	-15.548	3.98	-0.20	-0.015
50	L_2 x T_3	186.90	2.34	-7.205	9.40	2.89	0.030	114.18	0.79	495.648**	3.23	2.68	0.027
51	L_3 x T_3	186.60	1.29	-3.637	8.83	3.44	0.032	94.78	0.07	230.465**	3.52	-1.86	0.018
52	L_4 x T_3	179.59	-0.48	16.386	11.49	1.75	-0.033	155.18	0.18	431.194**	3.34	-4.43	-0.014
53	L_5 x T_3	190.83	-0.59	242.782**	10.79	-1.05	-0.025	180.85	1.53	46.529	4.09	1.95*	-0.020
54	L_6 x T_3	184.28	1.63	-15.497	9.66	3.18	0.049	117.74	1.26	-2.707	3.84	1.44	0.535**
55	L_7 x T_3	190.18	0.90	54.186*	9.70	2.71	0.059	116.19	1.08	528.879**	3.91	8.93	-0.008
56	L_8 x T_3	175.71	-0.63	43.913	9.73	-1.75	0.072	103.33	1.14	939.231**	3.46	2.99	-0.006
57	L_9 x T_3	193.08	2.66	5.425	10.90	1.07	0.025	174.20	1.51	128.285*	3.82	2.77	-0.018
58	L_{10} x T_3	176.05	-0.66	145.025**	8.52	0.29	0.116*	85.95	1.44	175.035*	3.23	-0.72	0.313**
59	L_{11} x T_3	184.17	1.82	-7.636	9.17	1.87	0.169*	106.20	2.82	-11.509	3.08	1.57	0.071*
60	L_{12} x T_3	179.68	1.74	2.692	9.53	2.97	0.001	123.43	-1.52	157.658*	4.14	1.96	0.008
61	L_{13} x T_3	178.82	2.41	-8.258	8.97	2.70	0.273**	91.24	2.64	308.361**	3.95	2.35	0.002
62	L_{14} x T_3	193.54	-0.50	175.345**	12.23	3.42*	-0.033	182.45	1.81	-33.649	3.24	4.75*	-0.018
63	L_{15} x T_3	190.27	0.59	105.070**	9.59	2.84	0.083	122.70	2.32	268.610**	3.92	2.65	-0.014
64	JA-20	185.85	0.59	-13.788	11.12	1.92	-0.024	157.63	0.21	3.624	3.76	0.59	0.039
65	JA-134	181.03	0.84	-9.546	11.02	2.37*	-0.036	161.54	1.82	-32.617	3.54	-1.67	0.192**

*, **, +, ++ significantly deviating from zero and unity at 5% and 1%, respectively

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(Table 2. Cont….)

S.No	Genotype	Root yield at harvest			Dry matter content of root			Test weight of seed			Total alkaloid content		
		μ	b	S²d	μ	b	S²d	μ	b	S²d	μ	b	S²d
1	T_1	9.78	-1.02	0.231	16.28	-5.09	1.160	2.11	1.82	0.000	0.32	-1.04	0.001**
2	T_2	13.85	1.78	-0.145	17.71	1.71	6.705*	2.27	0.01	0.013*	0.35	1.42	0.002**
3	T_3	17.77	1.04	0.653	23.81	3.49	11.450**	2.30	4.62	0.008	0.39	1.87	0.001**
4	L_1	10.78	2.48	-0.011	23.18	6.48	3.291	2.13	-0.86	0.012*	0.27	3.21	0.000**
5	L_2	11.59	2.80*	-0.327	18.16	5.98	5.729*	1.73	1.01	0.005	0.34	-1.10	0.000**
6	L_3	10.41	1.37	-0.319	22.97	-0.17	-1.035	2.05	0.22	0.025**	0.33	1.12	0.001**
7	L_4	6.82	-0.42	0.148	25.07	-5.03	-0.675	1.98	-2.40	0.003	0.32	0.91	0.001**
8	L_5	14.63	-0.73	-0.197	25.95	-1.16	14.028**	2.34	-1.94	-0.002	0.43	3.01	-0.000
9	L_6	6.81	1.31	-0.032	19.61	3.55	-0.784	1.66	-2.42	0.008	0.33	-0.70	0.001**
10	L_7	7.89	1.60	0.028	28.83	4.76	19.412**	1.96	0.06	0.005	0.30	-1.21	0.002**
11	L_8	15.02	0.85	5.475**	22.02	-1.53	28.181**	2.07	-3.24	0.010*	0.31	3.86	0.000
12	L_9	14.13	-1.21	0.663	26.67	-8.11	14.023**	2.38	0.56	-0.001	0.40	-0.68	0.000**
13	L_{10}	8.38	-1.23	5.999**	29.80	-3.02	43.734**	1.94	-2.60	0.011*	0.25	1.74	0.000*
14	L_{11}	7.50	2.16	-0.112	15.26	1.68	6.618*	1.92	1.10	0.009*	0.27	2.35	0.000*
15	L_{12}	7.59	0.12	-0.151	32.47	-9.44	0.285	2.10	4.28	0.003	0.25	2.33	0.000**
16	L_{13}	6.85	1.67	-0.320	24.81	7.00	65.523**	1.90	3.50	0.003	0.33	1.24	0.001**
17	L_{14}	14.33	0.77	-0.190	24.58	1.69	7.316**	2.36	-2.75	-0.001	0.42	2.76	0.001**
18	L_{15}	14.99	2.01	-0.056	23.25	1.32	4.139*	2.01	1.52	-0.001	0.38	-2.83	0.000**
19	L_1 x T_1	10.42	2.50	0.352	22.19	9.28	6.705*	2.07	4.76	0.038**	0.28	-2.18	0.000**
20	L_2 x T_1	9.19	-0.28	0.016	21.38	-2.28	0.067	1.86	1.60	0.039**	0.28	1.30	-0.000
21	L_3 x T_1	8.26	1.90	-0.198	24.49	3.89	-0.353	1.82	0.60	-0.001	0.34	3.66	0.000
22	L_4 x T_1	8.53	1.52	1.413*	23.91	-1.12	3.334	1.96	-0.88	0.002	0.32	2.65	0.001**
23	L_5 x T_1	16.77	0.93	0.075	22.27	-0.98	-0.483	1.94	-0.39	0.009*	0.38	-2.16+	-0.000
24	L_6 x T_1	7.73	-0.25	0.636	22.58	-6.15	0.178	2.03	0.22	0.008	0.32	2.36	0.000
25	L_7 x T_1	7.47	1.58	-0.121	26.16	-1.16	-0.201	2.12	2.80	0.005	0.38	-2.39	0.000**
26	L_8 x T_1	15.55	-0.89	5.214**	17.37	-5.31	13.308**	2.20	7.10	0.018**	0.34	2.54	0.001**
27	L_9 x T_1	13.40	1.14	5.147**	27.03	0.03	32.181**	1.99	0.10	0.018**	0.41	3.39	0.001**
28	L_{10} x T_1	7.57	0.76	2.874**	26.96	-1.46	-0.991	1.93	5.55	0.019**	0.33	1.43	0.002**
29	L_{11} x T_1	11.16	1.61	-0.286	14.81	0.00	-1.069	1.98	1.63	0.024**	0.27	-1.13	0.001**
30	L_{12} x T_1	11.88	-1.45	0.235	22.10	-8.70*+	-1.190	2.18	2.44	-0.002	0.31	3.30	0.002**
31	L_{13} x T_1	8.70	0.91	-0.007	21.28	4.84	8.187**	1.97	4.19	0.020**	0.31	3.86	0.000
32	L_{14} x T_1	13.10	-0.62	1.502*	25.93	-1.11	17.376**	2.04	-1.98	0.015*	0.37	0.90	0.001**
33	L_{15} x T_1	14.20	1.23	2.351**	17.06	0.46	2.718	1.99	3.67	0.006	0.33	1.11	0.000**
34	L_1 x T_2	13.94	3.42	0.000	21.48	6.79	6.117*	1.96	1.35	0.041**	0.29	2.44	0.002**
35	L_2 x T_2	11.79	2.36*	-0.339	20.67	7.63	1.069	1.86	-2.17	0.009*	0.32	1.78	0.001**
36	L_3 x T_2	8.21	0.43	-0.101	23.49	-1.21	0.026	2.06	1.47	0.014*	0.29	-0.81	0.001**
37	L_4 x T_2	8.11	1.46	-0.288	26.00	2.48	19.125**	2.00	0.44	0.027**	0.35	1.44	0.002**
38	L_5 x T_2	13.38	1.09	-0.174	29.38	-0.69	-0.999	2.34	-0.28	-0.001	0.43	0.46	0.000**
39	L_6 x T_2	13.73	2.14	0.459	17.65	3.94	7.036**	1.85	4.28	0.026**	0.29	-2.57	0.000**
40	L_7 x T_2	11.07	1.96	3.107**	21.88	5.50	-1.009	2.06	-0.58	0.051**	0.32	-5.36	0.000**
41	L_8 x T_2	13.88	1.17	4.533**	20.89	1.16	31.442**	2.06	5.92	0.029**	0.34	3.01*+	-0.000
42	L_9 x T_2	14.75	0.44	0.642	28.31	-0.35	5.713*	2.14	-1.13	0.024**	0.44	1.34	0.001**
43	L_{10} x T_2	8.42	-0.26	-0.104	26.53	-2.82	35.970**	2.10	-4.18	0.033**	0.39	4.75	0.000*
44	L_{11} x T_2	9.95	-1.10	0.580	19.69	-4.74	-0.939	2.20	3.98	0.006	0.34	1.55	0.001**
45	L_{12} x T_2	12.67	1.87	0.629	21.59	3.99	-0.978	1.99	2.04	0.015*	0.28	2.60	0.000**
46	L_{13} x T_2	13.24	1.79*	-0.348	17.44	6.40	16.805**	2.11	1.78	0.009*	0.36	1.95	0.000**
47	L_{14} x T_2	14.59	0.56	0.235	26.59	2.87	-0.870	2.34	3.59	-0.003	0.40	-0.38	0.001**
48	L_{15} x T_2	14.24	-1.41	3.376**	23.93	1.10	3.206	2.09	3.57	0.001	0.40	-2.17	0.000*
49	L_1 x T_3	15.95	2.03	-0.319	24.51	3.01	10.140**	2.23	1.83	-0.002	0.38	2.43	0.001**
50	L_2 x T_3	14.14	1.16	9.704**	19.88	-0.48	33.962**	2.04	0.22	0.006	0.30	-1.33	0.001**
51	L_3 x T_3	11.65	1.69	-0.181	23.28	0.88	2.151	1.99	-2.64	0.002	0.31	-1.02	0.001**
52	L_4 x T_3	12.64	-2.39+	-0.306	24.33	-7.39	-0.911	2.25	-2.79	0.029**	0.35	-4.73*+	0.000
53	L_5 x T_3	16.10	3.53	1.313*	27.51	3.43	5.855*	2.32	1.00	-0.003	0.48	2.38	0.000**
54	L_6 x T_3	10.85	1.58	0.242	25.82	7.17	10.575**	1.91	-1.47	0.028**	0.37	0.37	0.001**
55	L_7 x T_3	8.69	1.38	-0.214	27.28	2.29	10.366**	2.05	1.75	0.038**	0.44	3.03	0.000*
56	L_8 x T_3	9.85	1.94	-0.322	27.84	4.64	1.320	1.90	2.89	0.001	0.42	-4.69	0.001**
57	L_9 x T_3	15.51	2.60	0.483	29.15	3.18	8.538**	2.29	-2.94	0.004	0.49	3.22*+	-0.000
58	L_{10} x T_3	10.23	1.18	4.429**	22.97	5.07	51.761**	1.99	4.75	0.033**	0.36	3.62	0.001**
59	L_{11} x T_3	11.50	1.07	6.007**	22.25	-1.09	14.889**	2.18	4.64	0.013*	0.30	-1.88	0.001**
60	L_{12} x T_3	14.14	1.96	6.790**	21.16	4.86	11.132**	2.13	4.36	0.030**	0.33	2.35	0.000**
61	L_{13} x T_3	12.68	1.02	8.812**	22.37	5.87	72.000**	1.94	3.62	0.011*	0.43	0.61	0.000**
62	L_{14} x T_3	14.89	0.81	0.908	28.31	3.48	-0.323	2.11	1.90	-0.002	0.47	2.30	0.002**
63	L_{15} x T_3	15.85	1.86	10.010**	21.91	2.32	32.807**	2.02	-3.09	0.008	0.43	5.20	0.000**
64	JA-20	14.62	0.47	-0.330	25.51	0.33	-0.533	2.18	-1.94	-0.002	0.41	1.68	0.000**
65	JA-134	14.90	1.24	-0.338	25.64	1.02	-1.200	2.15	-1.02	-0.001	0.43	4.53	0.000**

*, **, +, ++ significantly deviating from zero and unity at 5% and 1%, respectively

Table 3. Stable genotypes identified with suitability in desirable direction for different characters of ashwagandha

S.No.	Characters	Different environments (b=1)	Above average environments (b <1)	Below average environments (b >1)
1	Days to 75 % Maturity	-	(T_2, T_3, L_4, L_6, L_7 & L_{15}), (JA-134), (L_7 x T_1, L_9 x T_1, L_7 x T_2, L_4 x T_3 & L_8 x T_3)	(T_1), (L_2 x T_1, L_4 x T_1, L_{10} x T_1, L_{11} x T_1, L_{13} x T_1, L_{15} x T_1, L_{13} x T_2, L_{12} x T_3 & L_{13} x T_3)
2	Number of secondary branches/ plant	(T_3)	(L_5 x T_1, L_1 x T_2, L_4 x T_2, L_5 x T_2, L_9 x T_2, L_{14} x T_2, L_5 x T_3 & L_8 x T_3)	(L_{15}), (JA-20 & JA-134), (L_9 x T_1, L_{15} x T_2, L_2 x T_3,L_4 x T_3, L_6 x T_3, L_7 x T_3, L_9 x T_3, L_{12} x T_3, L_{14} x T_3 , & L_{15} x T_3)
3	Number of berries/ plant	(L_5 x T_1)	(L_5, L_9 & L_{14}), (JA-20)	(T_2, T_3 & L_1), (JA-134), (L_9 x T_1, L_{14} x T_1, L_9 x T_2, L_{14} x T_2, L_1 x T_3, L_5 x T_3, L_6 x T_3 & L_{14} x T_3)
4	Number of secondary and tertiary roots/ plant	-	(T_3), (JA-20), (L_2 x T_1, L_5 x T_1, L_9 x T_1, L_7 x T_2 & L_1 x T_3)	(L_9), (L_1 x T_1, L_8 x T_1, L_{15} x T_1, L_5 x T_2, L_9 x T_2, L_{15} x T_2, L_5 x T_3, L_7 x T_3, L_9 x T_3, L_{12} x T_3, L_{13} x T_3 & L_{15} x T_3)
5	Root yield at harvest	(T_3)	(L_5, L_9 & L_{14}), (JA-20), (L_5 x T_1, L_{12} x T_1, L_9 x T_2, L_{14} x T_2, L_4 x T_3 & L_{14} x T_3)	(L_{15}), (JA-134), (L_1 x T_2, L_5 x T_2, L_6 x T_2, L_{12} x T_2, L_{13} x T_2, L_1 x T_3 & L_9 x T_3)
6	Dry matter content of root	(JA-134)	(L_4 & L_{12}), (JA-20), (L_4 x T_1, L_7 x T_1, L_{10} x T_1, L_3 x T_2, L_5 x T_2 & L_4 x T_3)	(L_3 x T_1, L_{14} x T_2, L_{15} x T_2, L_8 x T_3 & L_{14} x T_3)
7	Test weight of seed	(L_5 x T_3)	(L_5, L_9 & L_{14}), (JA-20 & JA-134), (L_5 x T_2 & L_9 x T_3)	(T_1, T_3 & L_{12}), (L_7 x T_1, L_{12} x T_1, L_{11} x T_2, L_{14} x T_2, L_{15} x T_2, L_1 x T_3 & L_{14} x T_3)
8	Total alkaloid content	-	(L_5 x T_1 & L_4 x T_3)	(L_5), (L_9 x T_3)

average environments, whereas, the parent *i.e.* L_9 and 12 hybrids *viz.,* L_1 x T_1, L_8 x T_1, L_{15} x T_1, L_5 x T_2, L_9 x T_2, L_{15} x T_2, L_5 x T_3, L_7 x T_3, L_9 x T_3, L_{12} x T_3, L_{13} x T_3, L_{15} x T_3 were found stable under below average environments.

Six hybrids *viz.,* L_5 x T_1, L_{12} x T_1, L_9 x T_2, L_{14} x T_2, L_4 x T_3, L_{14} x T_3 and one check (JA-20) showed stability under unfavorable environment, whereas one parent i.e. L_{15} and seven crosses *viz*., L_1 x T_2, L_5 x T_2, L_6 x T_2, L_{12} x T_2, L_{13} x T_2, L_1 x T_3, L_9 x T_3 along with the check (JA-134) showed the performance as stable in favorable environments, while T_3 was found suitable for general cultivation across the environments for higher root yield at harvest. Two parents (L_4 and L_{12}) and 6 hybrids *viz.,* L_4 x T_1, L_7 x T_1, L_{10} x T_1, L_3 x T_2, L_5 x T_2, L_4 x T_3 along with one check (JA-20) exhibited stability with suitability under poor environmental condition, while the check (JA-134) indicated its average stability for general cultivation, whereas five hybrids *viz.,* L_3 x T_1, L_{14} x T_2, L_{15} x T_2, L_8 x T_3 and L_{14} x T_3 were considered stable under below average environment for higher dry matter content of root. Three parents *viz.,* L_5, L_9, L_{14} and two hybrids *viz.,* L_5 x T_2, L_9 x T_3 along with both the checks were reported suitable with specific adaptation to unfavorable environments, while another three parents, T_1, T_3, L_{12} and seven hybrids *viz.,* L_7 x T_1, L_{12} x T_1, L_{11} x T_2, L_{14} x T_2, L_{15} x T_2, L_1 x T_3, L_{14} x T_3 exhibited their stability under favorable environments, whereas, the only cross i.e. L_5 x T_3 showed average stability for higher test weight of seed. For total alkaloid content, two hybrids *viz.,* L_5 x T_1 and L_4 x T_3 exhibited non-significant deviation from regression (S^2d) and regression coefficient less than unity (b <1) with higher mean value than the population mean, hence they were considered suitable and stable in unfavorable environments, while L_5 and L_9 x T_3 showed their suitability along with stable performance under favorable environment. On the basis of G x E interaction study (**Table 3**), few genotypes were identified stable for general cultivation across the environments with high *per se* performance in desirable directions *viz.,* T_3 for number of secondary branches per plant and root yield at harvest; L_5 x T_1 for number of berries per plant; JA- 134 for dry matter content of root; L_5 x T_3 for test weight of seed.

Among the lines, the above average stability for root yield at harvest showed by L_5, L_9 & L_1 whereas for total alkaloid content below average stability was showed by L_5. Among the testers, T_3 was identified with above average stability for days to 75 % maturity along with number of secondary and tertiary roots per plant, while it showed below average stability for numbers of berries per plant and test weight of seed; Among the checks, JA-134 was exhibited below average stability and JA-20 showed above average stability for root yield at harvest. For root yield at harvest, along with total alkaloid content, out of the crosses, above average stability was depicted by L_5 x T_1 and L_4 x T_3 and L_9 x T_3 could be suitable for below average environments. In the study it was observed that root yield and alkaloid content were highly influenced by genotype x environmental interactions.

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