

Supplementary files

# Heterosis Studies for Root-Yield-Attributing Characters and Total Alkaloid Content over Different Environments in *Withania somnifera* L.

Iqbal Ahmed <sup>1</sup>, Rajendra Babu Dubey <sup>1</sup>, Devendra Jain <sup>2\*</sup>, Mohamed A. El-Sheikh <sup>3</sup> and Prashant Kaushik <sup>4</sup>

<sup>1</sup> Department of Genetics and Plant Breeding, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur, India

<sup>2</sup> Department of Molecular Biology and Biotechnology, Rajasthan College of Agriculture, Maharana Pratap University of Agriculture and Technology, Udaipur, India

<sup>3</sup> Botany and Microbiology Department, College of Science, King Saud University, Riyadh, Saudi Arabia

<sup>4</sup> Instituto de Conservación y Mejora de la Agrodiversidad Valenciana, Universitat Politècnica de València, 46022 Valencia, Spain

\* Correspondence: devroshan@gmail.com or devendrajain@mpuat.ac.in; Tel.: +91-992-984-0357

**Supplementary data sheet Table S1:** Extent of heterosis for number of secondary branches per plant

SN.	Crosses	Heterosis				Heterobeltiosis				Economic Heterosis			
		E <sub>1</sub>	E <sub>2</sub>	E <sub>3</sub>	Pool	E <sub>1</sub>	E <sub>2</sub>	E <sub>3</sub>	Pool	E <sub>1</sub>	E <sub>2</sub>	E <sub>3</sub>	Pool
1.	L <sub>1</sub> × T <sub>1</sub>	24.83**	9.16**	3.21	12.21**	11.84**	0.88	3.19	5.31**	-	-	-	-
2.	L <sub>2</sub> × T <sub>1</sub>	30.40**	16.58**	19.12**	21.80**	22.95**	10.54**	-	10.39**	-	-	-	-
3.	L <sub>3</sub> × T <sub>1</sub>	31.41**	25.45**	26.25**	27.64**	30.48**	19.60**	11.88**	20.15**	-	-	-	-
4.	L <sub>4</sub> × T <sub>1</sub>	29.91**	15.00**	16.61**	20.31**	20.05**	2.94	-	6.24**	-	-	-	-
5.	L <sub>5</sub> × T <sub>1</sub>	24.77**	6.05**	19.13**	16.23**	2.16	-	7.63**	-	-	-	1.88	-
6.	L <sub>6</sub> × T <sub>1</sub>	18.95**	21.33**	14.86**	18.30**	13.00**	-	-	2.21	-	-	-	-
7.	L <sub>7</sub> × T <sub>1</sub>	21.85**	23.20**	24.93**	23.34**	21.27**	14.64**	10.71**	15.60**	-	-	-	-
8.	L <sub>8</sub> × T <sub>1</sub>	20.98**	4.43	0.92	8.43**	12.11**	-	0.04	3.34	-	-	-	-
9.	L <sub>9</sub> × T <sub>1</sub>	25.00**	15.03**	13.32**	17.65**	-	-	-	-	6.32**	7.78**	7.56**	7.21**
10.	L <sub>10</sub> × T <sub>1</sub>	26.11**	23.98**	10.49**	20.07**	26.05**	16.75**	-	13.13**	-	-	-	-
11.	L <sub>11</sub> × T <sub>1</sub>	29.23**	22.40**	19.65**	23.63**	18.33**	10.41**	-	8.88**	-	-	-	-
12.	L <sub>12</sub> × T <sub>1</sub>	27.88**	11.93**	17.23**	18.68**	27.67**	9.70**	9.34**	16.57**	-	-	-	-
13.	L <sub>13</sub> × T <sub>1</sub>	19.58**	16.27**	6.75*	13.87**	12.57**	1.04	-	3.28	-	-	-	-
14.	L <sub>14</sub> × T <sub>1</sub>	16.96**	12.34**	5.62*	11.54**	-	-	-	-	3.76	-	3.92	1.98
15.	L <sub>15</sub> × T <sub>1</sub>	-19.27**	-11.88**	1.22	-10.05**	-	-	-	-	-	-	-	-
16.	L <sub>1</sub> × T <sub>2</sub>	4.60	7.88**	9.06**	7.17**	4.27	7.29*	3.64	5.46**	-	-	-	-
17.	L <sub>2</sub> × T <sub>2</sub>	22.99**	9.38**	29.09**	20.21**	4.35	-	3.60	1.56	-	-	-	-
18.	L <sub>3</sub> × T <sub>2</sub>	13.65**	19.58**	14.02**	15.78**	0.90	6.30*	-	1.26	-	-	-	-
19.	L <sub>4</sub> × T <sub>2</sub>	28.90**	32.80**	33.70**	31.80**	7.46*	11.41**	7.42*	8.76**	-	-	-	-
20.	L <sub>5</sub> × T <sub>2</sub>	23.16**	14.05**	24.36**	20.30**	11.48**	-	17.91**	8.28**	6.96**	10.72**	11.61**	9.72**
21.	L <sub>6</sub> × T <sub>2</sub>	23.71**	26.43**	23.49**	24.51**	5.66	-	-	0.71	-	-	-	-
22.	L <sub>7</sub> × T <sub>2</sub>	16.52**	12.70**	18.69**	15.97**	4.53	-	0.62	1.02	-	-	-	-
23.	L <sub>8</sub> × T <sub>2</sub>	23.86**	22.59**	6.84*	17.73**	19.03**	20.89**	2.37	14.01**	-	-	-	-
24.	L <sub>9</sub> × T <sub>2</sub>	-2.45	-2.57	2.79	-0.77	-	-	-	-	-	-	1.91	-
25.	L <sub>10</sub> × T <sub>2</sub>	10.51**	5.82*	15.41**	10.56**	-	-	-	-	-	-	-	-
26.	L <sub>11</sub> × T <sub>2</sub>	16.83**	18.68**	22.66**	19.37**	-	0.26	-	-	-	-	-	-
27.	L <sub>12</sub> × T <sub>2</sub>	15.92**	5.63*	9.18**	10.13**	3.41	0.00	-	0.15	-	-	-	-
28.	L <sub>13</sub> × T <sub>2</sub>	21.56**	13.40**	12.66**	15.83**	3.00	-	-	-	-	-	-	-
29.	L <sub>14</sub> × T <sub>2</sub>	17.27**	25.33**	15.82**	19.34**	-	10.63**	-	2.09	13.75**	16.83**	18.86**	16.43**
30.	L <sub>15</sub> × T <sub>2</sub>	22.80**	21.16**	17.88**	20.67**	10.79**	11.48**	15.75**	12.53**	7.08**	7.25**	1.88	5.45**
31.	L <sub>1</sub> × T <sub>3</sub>	0.32	-6.34**	-0.64	-2.25	-	-	-	-	-	-	-	-
32.	L <sub>2</sub> × T <sub>3</sub>	1.73	-6.60**	-3.52	-2.82*	-	-	-	-	-	-	-	-
33.	L <sub>3</sub> × T <sub>3</sub>	-6.71**	-12.41**	-14.58**	-11.18**	-	-	-	-	-	-	-	-
34.	L <sub>4</sub> × T <sub>3</sub>	22.06**	20.19**	20.82**	21.03**	-	-	-	-	2.68	3.56	3.55	3.26*
35.	L <sub>5</sub> × T <sub>3</sub>	-12.80**	-15.78**	-5.35**	-11.49**	-	-	-	-	-	-	1.54	-
36.	L <sub>6</sub> × T <sub>3</sub>	0.93	11.13**	-1.80	3.33*	-	-	-	-	-	-	-	-
37.	L <sub>7</sub> × T <sub>3</sub>	0.47	-2.70	-4.02	-2.04	-	-	-	-	-	-	-	-
38.	L <sub>8</sub> × T <sub>3</sub>	-9.94**	-14.12**	-5.25*	-9.80**	-	-	-	-	-	-	-	-
39.	L <sub>9</sub> × T <sub>3</sub>	-15.48**	-14.96**	-15.41**	-15.28**	-	-	-	-	-	0.18	-	-
40.	L <sub>10</sub> × T <sub>3</sub>	-13.44**	-17.31**	-12.10**	-14.30**	-	-	-	-	-	-	-	-
41.	L <sub>11</sub> × T <sub>3</sub>	1.17	-7.64**	-3.11	-3.21*	-	-	-	-	-	-	-	-
42.	L <sub>12</sub> × T <sub>3</sub>	-1.08	-9.75**	-10.07**	-7.00**	-	-	-	-	-	-	-	-
43.	L <sub>13</sub> × T <sub>3</sub>	-7.68**	1.69	-15.30**	-7.24**	-	-	-	-	-	-	-	-
44.	L <sub>14</sub> × T <sub>3</sub>	-5.01**	0.25	-10.64**	-5.21**	-	-	-	-	10.49**	11.86**	7.38**	9.94**
45.	L <sub>15</sub> × T <sub>3</sub>	-19.90**	-15.84**	-19.76**	-18.49**	-	-	-	-	-	-	-	-

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

**Supplementary data sheet Table S2:** Extent of heterosis for number of berries per plant

SN.	Crosses	Heterosis				Heterobeltiosis				Economic Heterosis			
		E <sub>1</sub>	E <sub>2</sub>	E <sub>3</sub>	Pool	E <sub>1</sub>	E <sub>2</sub>	E <sub>3</sub>	Pool	E <sub>1</sub>	E <sub>2</sub>	E <sub>3</sub>	Pool
1.	L <sub>1</sub> × T <sub>1</sub>	-1.36	-19.25**	-1.41	-7.34	-	-	-	-	-	-	-	-
2.	L <sub>2</sub> × T <sub>1</sub>	-11.53	-3.92	25.64**	3.22	-	-	10.40	-	-	-	-	-
3.	L <sub>3</sub> × T <sub>1</sub>	24.58**	10.45	36.92**	23.79**	21.13*	3.71	18.03*	16.36**	-	-	-	-
4.	L <sub>4</sub> × T <sub>1</sub>	8.50	-9.69	-20.31*	-7.79	-	-	-	-	-	-	-	-
5.	L <sub>5</sub> × T <sub>1</sub>	25.61**	10.29	16.27**	17.39**	-	-	-	-	-	-	-	-
6.	L <sub>6</sub> × T <sub>1</sub>	-2.83	-11.39	-7.75	-7.29	-	-	-	-	-	-	-	-
7.	L <sub>7</sub> × T <sub>1</sub>	-0.51	15.85	-15.99	-0.46	-	3.54	-	-	-	-	-	-
8.	L <sub>8</sub> × T <sub>1</sub>	-17.98*	18.98*	-12.41	-4.32	-	13.95	-	-	-	-	-	-
9.	L <sub>9</sub> × T <sub>1</sub>	33.23**	19.27**	-1.52	16.48**	2.29	-	-	-	-	-	-	-
10.	L <sub>10</sub> × T <sub>1</sub>	16.72	-36.63**	-14.54	-12.02*	15.03	-	-	-	-	-	-	-
11.	L <sub>11</sub> × T <sub>1</sub>	13.62	-23.97**	-6.79	-6.46	2.71	-	-	-	-	-	-	-
12.	L <sub>12</sub> × T <sub>1</sub>	32.19**	40.76**	10.64	27.70**	31.21**	31.24**	1.70	21.46**	-	-	-	-
13.	L <sub>13</sub> × T <sub>1</sub>	-1.83	-18.38*	24.34*	0.37	-	-	-	-	-	-	-	-
14.	L <sub>14</sub> × T <sub>1</sub>	23.98**	10.98*	-7.12	8.94**	-	-	-	-	-	-	-	-
15.	L <sub>15</sub> × T <sub>1</sub>	-4.55	-17.18**	-19.39**	-13.83**	-	-	-	-	-	-	-	-
16.	L <sub>1</sub> × T <sub>2</sub>	-14.54**	0.85	-17.91**	-10.40**	-	-	-	-	-	-	-	-
17.	L <sub>2</sub> × T <sub>2</sub>	0.32	-12.48	-13.35	-8.22*	-	-	-	-	-	-	-	-
18.	L <sub>3</sub> × T <sub>2</sub>	-24.97**	-8.17	-28.37**	-20.28**	-	-	-	-	-	-	-	-
19.	L <sub>4</sub> × T <sub>2</sub>	1.08	-2.44	-5.27	-2.17	-	-	-	-	-	-	-	-
20.	L <sub>5</sub> × T <sub>2</sub>	-12.14**	-3.65	-13.86**	-9.83**	-	-	-	-	-	-	-	-
21.	L <sub>6</sub> × T <sub>2</sub>	-24.20**	-4.64	-3.66	-11.41**	-	-	-	-	-	-	-	-
22.	L <sub>7</sub> × T <sub>2</sub>	-11.03	-24.70**	-25.44**	-20.15**	-	-	-	-	-	-	-	-
23.	L <sub>8</sub> × T <sub>2</sub>	4.45	-21.52**	0.60	-5.21	-	-	-	-	-	-	-	-
24.	L <sub>9</sub> × T <sub>2</sub>	9.74*	-2.82	-11.69*	-1.52	6.29	-	-	-	-	-	-	-
25.	L <sub>10</sub> × T <sub>2</sub>	-13.34*	-36.62**	-5.40	-19.18**	-	-	-	-	-	-	-	-
26.	L <sub>11</sub> × T <sub>2</sub>	-8.82	-34.89**	-18.92**	-21.10**	-	-	-	-	-	-	-	-
27.	L <sub>12</sub> × T <sub>2</sub>	6.33	-14.76*	11.26	0.82	-	-	-	-	-	-	-	-
28.	L <sub>13</sub> × T <sub>2</sub>	-2.12	-19.36**	-19.71*	-13.21**	-	-	-	-	-	-	-	-
29.	L <sub>14</sub> × T <sub>2</sub>	19.13**	5.57	8.91	11.16**	13.92**	-	-	1.98	7.97	5.85	8.31	8.44**
30.	L <sub>15</sub> × T <sub>2</sub>	2.56	-4.19	-14.07*	-4.93	-	-	-	-	-	-	-	-
31.	L <sub>1</sub> × T <sub>3</sub>	-2.16	-2.55	-8.51	-4.26	-	-	-	-	-	-	-	-
32.	L <sub>2</sub> × T <sub>3</sub>	-20.52**	0.51	-19.17**	-13.07**	-	-	-	-	-	-	-	-
33.	L <sub>3</sub> × T <sub>3</sub>	-36.73**	-18.03**	-27.84**	-27.76**	-	-	-	-	-	-	-	-
34.	L <sub>4</sub> × T <sub>3</sub>	15.41**	32.45**	17.97**	22.05**	-	-	-	-	-	6.17	-	-
35.	L <sub>5</sub> × T <sub>3</sub>	3.26	8.22	0.99	4.19	-	3.02	-	-	8.53	15.11**	8.95	11.95**
36.	L <sub>6</sub> × T <sub>3</sub>	-7.39	-12.54*	-2.37	-7.60*	-	-	-	-	-	-	-	-
37.	L <sub>7</sub> × T <sub>3</sub>	-4.18	-24.64**	-2.49	-10.35**	-	-	-	-	-	-	-	-
38.	L <sub>8</sub> × T <sub>3</sub>	-17.47**	-42.22**	-17.59**	-25.45**	-	-	-	-	-	-	-	-
39.	L <sub>9</sub> × T <sub>3</sub>	7.16	-4.63	0.23	0.99	-	-	-	-	8.93	0.09	11.42*	7.84*
40.	L <sub>10</sub> × T <sub>3</sub>	-34.08**	-28.15**	-40.24**	-33.88**	-	-	-	-	-	-	-	-
41.	L <sub>11</sub> × T <sub>3</sub>	-5.30	-17.66**	-29.97**	-17.40**	-	-	-	-	-	-	-	-
42.	L <sub>12</sub> × T <sub>3</sub>	-15.87**	-13.70*	10.97	-6.65*	-	-	-	-	-	-	-	-
43.	L <sub>13</sub> × T <sub>3</sub>	-16.70**	-43.13**	-25.39**	-28.30**	-	-	-	-	-	-	-	-
44.	L <sub>14</sub> × T <sub>3</sub>	8.92*	1.15	-0.27	3.31	0.94	0.40	-	0.56	12.08*	12.18*	11.18*	12.94**
45.	L <sub>15</sub> × T <sub>3</sub>	-9.94*	-34.31**	-19.31**	-21.31**	-	-	-	-	-	-	-	-

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

**Supplementary data sheet Table S3:** Extent of heterosis for harvest index

SN.	Crosses	Heterosis				Heterobeltiosis				Economic Heterosis			
		E <sub>1</sub>	E <sub>2</sub>	E <sub>3</sub>	Pool	E <sub>1</sub>	E <sub>2</sub>	E <sub>3</sub>	Pool	E <sub>1</sub>	E <sub>2</sub>	E <sub>3</sub>	Pool
1.	L <sub>1</sub> × T <sub>1</sub>	-11.78	31.20**	45.06**	20.44**	-	16.36	19.01	2.54	-	0.60	7.71	-
2.	L <sub>2</sub> × T <sub>1</sub>	28.74**	41.26**	9.84	27.08**	27.53*	24.76*	-	14.75*	-	8.90	-	-
3.	L <sub>3</sub> × T <sub>1</sub>	11.46	-11.69	20.85	5.86	-	-	1.79	-	11.42	-	-	-
4.	L <sub>4</sub> × T <sub>1</sub>	40.25**	40.31**	28.15*	36.51**	25.43**	26.95*	11.05	21.36**	12.68	4.90	-	2.29
5.	L <sub>5</sub> × T <sub>1</sub>	33.12**	8.76	31.90**	23.69**	22.11*	-	11.14	5.90	3.66	-	-	-
6.	L <sub>6</sub> × T <sub>1</sub>	36.80**	23.52*	44.23**	34.16**	34.19**	10.62	33.31*	26.33**	-	-	-	-
7.	L <sub>7</sub> × T <sub>1</sub>	12.22	-5.17	19.88*	8.63	-	-	-	-	13.85	-	-	-
8.	L <sub>8</sub> × T <sub>1</sub>	28.36**	27.49**	49.11**	34.26**	3.44	6.79	23.24*	10.44*	19.82*	5.79	9.46	12.25*
9.	L <sub>9</sub> × T <sub>1</sub>	47.85**	21.73*	32.19**	34.05**	24.66**	2.82	11.47	13.10*	28.70**	-	-	7.89
10.	L <sub>10</sub> × T <sub>1</sub>	-7.22	11.36	-10.67	-2.44	-	-	-	-	11.18	11.15	-	5.00
11.	L <sub>11</sub> × T <sub>1</sub>	1.56	54.29**	47.28**	33.10**	-	34.95**	39.05*	22.56**	-	-	-	-
12.	L <sub>12</sub> × T <sub>1</sub>	-20.41**	31.87**	11.31	5.04	-	14.78	-	-	-	3.65	-	-
13.	L <sub>13</sub> × T <sub>1</sub>	-3.69	53.41**	10.40	18.74**	-	35.88**	-	-	-	17.82*	-	-
14.	L <sub>14</sub> × T <sub>1</sub>	7.64	-5.99	43.81**	14.86**	-	-	12.38	-	-	-	15.80	-
15.	L <sub>15</sub> × T <sub>1</sub>	11.68	6.33	8.00	8.71	-	-	-	-	-	-	-	-
16.	L <sub>1</sub> × T <sub>2</sub>	7.73	18.41*	8.89	11.59*	-	9.99	-	0.38	-	-	-	-
17.	L <sub>2</sub> × T <sub>2</sub>	16.15	20.03*	37.45**	24.57**	11.06	11.01	26.25*	19.36**	-	-	4.39	-
18.	L <sub>3</sub> × T <sub>2</sub>	6.77	0.53	7.17	4.70	-	-	-	-	11.15	-	-	-
19.	L <sub>4</sub> × T <sub>2</sub>	30.93**	8.13	33.58**	24.08**	23.13*	2.59	25.23*	16.92**	10.61	-	-	-
20.	L <sub>5</sub> × T <sub>2</sub>	53.27**	3.57	26.76**	26.74**	48.07**	-	15.21	14.70**	25.70**	-	-	5.58
21.	L <sub>6</sub> × T <sub>2</sub>	54.72**	7.44	17.26	25.73**	43.99**	0.84	16.53	25.46**	13.94	-	-	-
22.	L <sub>7</sub> × T <sub>2</sub>	10.29	-2.23	-5.83	1.24	-	-	-	-	16.46	-	-	-
23.	L <sub>8</sub> × T <sub>2</sub>	12.03	3.47	4.93	6.99	-	-	-	-	9.21	-	-	-
24.	L <sub>9</sub> × T <sub>2</sub>	41.07**	14.52	38.74**	31.22**	24.60**	1.03	26.20*	16.89**	28.64**	-	6.62	11.50*
25.	L <sub>10</sub> × T <sub>2</sub>	-33.97**	3.53	9.62	-7.96*	-	-	-	-	-	7.10	17.78*	3.20
26.	L <sub>11</sub> × T <sub>2</sub>	39.07**	50.72**	36.74**	42.15**	25.16*	26.30*	19.26	23.69**	-	-	-	-
27.	L <sub>12</sub> × T <sub>2</sub>	-21.70**	-3.81	14.62	-5.05	-	-	-	-	-	-	-	-
28.	L <sub>13</sub> × T <sub>2</sub>	-23.81**	2.45	11.30	-4.59	-	-	-	-	-	-	-	-
29.	L <sub>14</sub> × T <sub>2</sub>	5.60	10.53	38.18**	18.01**	-	-	15.50	1.97	-	-	19.01*	4.41
30.	L <sub>15</sub> × T <sub>2</sub>	-5.96	15.27	34.30**	14.03**	-	0.87	15.47	-	-	-	11.07	0.32
31.	L <sub>1</sub> × T <sub>3</sub>	11.44	-13.07	-16.19*	-6.24	9.61	-	-	-	11.45	-	-	-
32.	L <sub>2</sub> × T <sub>3</sub>	16.24	-16.70*	-9.47	-4.58	0.79	-	-	-	-	-	-	-
33.	L <sub>3</sub> × T <sub>3</sub>	1.62	-24.49**	-11.76	-11.78**	-	-	-	-	15.56	-	-	-
34.	L <sub>4</sub> × T <sub>3</sub>	13.19	-19.09*	-13.19	-6.87	8.29	-	-	-	6.51	-	-	-
35.	L <sub>5</sub> × T <sub>3</sub>	22.53**	-5.43	3.77	5.92	14.15	-	-	-	12.26	3.02	1.81	6.25
36.	L <sub>6</sub> × T <sub>3</sub>	12.95	5.03	16.76*	11.30*	-	-	-	-	-	3.91	5.05	1.73
37.	L <sub>7</sub> × T <sub>3</sub>	-0.21	-16.06*	-10.91	-9.08*	-	-	-	-	14.96	-	-	1.16
38.	L <sub>8</sub> × T <sub>3</sub>	10.63	-24.25**	26.09**	3.60	2.28	-	13.23	0.30	18.47*	-	26.35**	8.89
39.	L <sub>9</sub> × T <sub>3</sub>	23.37**	-7.98	6.71	6.88	20.45*	-	-	0.39	24.35**	-	4.62	9.00
40.	L <sub>10</sub> × T <sub>3</sub>	-21.93**	-33.48**	-18.47**	-24.52**	-	-	-	-	4.29	-	4.87	-
41.	L <sub>11</sub> × T <sub>3</sub>	25.77**	27.39**	3.25	18.70**	3.35	-	-	-	1.65	4.11	-	-
42.	L <sub>12</sub> × T <sub>3</sub>	-34.15**	-14.58*	1.31	-16.37**	-	-	-	-	-	-	7.77	-
43.	L <sub>13</sub> × T <sub>3</sub>	-7.17	-16.18*	-9.10	-10.76*	-	-	-	-	1.86	-	-	-
44.	L <sub>14</sub> × T <sub>3</sub>	11.99	13.27	15.50*	13.64**	8.62	5.49	11.07	10.41*	13.67	19.53*	23.94**	19.87**
45.	L <sub>15</sub> × T <sub>3</sub>	-4.78	-8.71	-20.93**	-11.57**	-	-	-	-	-	-	-	-

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