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Character association and path analysis in Brahmi (*Bacopa monnieri* L.)

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Abstract
The present investigation were undertaken to study the correlation and path analysis in 50 germplasm lines of Brahmi. The germplasm was laid in Augmented Block Design with 50 germplasm lines of Brahmi along with two checks and the interrelationship among the herbage yield and yield attributing traits, Bacoside A were analysed. Dry herbage yield per plot exhibited positive and significant association with number of primary branches per plant and fresh herbage yield at genotypic and phenotypic level. Path analysis revealed that Bacoside A had the higher positive direct effect on yield followed by fresh herbage yield, number of primary branches per plant at phenotypic and genotypic level.

Keywords: Brahmi, yield and quality attributes, character association, path analysis

Introduction

India's traditional health care practices are well represented in classic systems of medicines like Ayurveda, Siddha, Unani and Swa-rigpa and also by local folk health practioners. *Bacopa monnieri*, is one of the high value medicinal plant considered as main rejuvenating herb, which played important role in Ayurvedic therapies. *Bacopa monnieri* (L.) Wettst. (Family: Scrophulariaceae), is one of the high value medicinal plant considered as the rejuvenating herb, which is a component in many Ayurvedic therapies (Kapil and Sharma, 2014) [4]. India is believed to be one of the natural centers of origins of the Bacopa in the world and it is distributed throughout Indian subcontinent (Karthikeyan *et al.*, 2011) [5]. *B. monnieri* was placed second in a priority list of the most important Indian medicinal plants evaluated on the basis of their medicinal importance, commercial value and potential for further research and development. It contains different types of saponins such as Bacosides A, B, C and D which are the active triterpenoid principles and known as "memory chemicals". Because of its inherent potential of enhancing memory and vitality, this miracle plant is gaining attention for its commercial cultivation commercially and globally. This plant is considered among one of the "Celestial drugs" (Divya aushadhi), when consumed with milk for six months. The medicinal properties and over exploitation necessitate, extensive cultivation of this crop. Existing knowledge on genetic potential of Brahmi and its related species are limited which hinders the improvement of these species as well as their sustainable conservation.

Importance of correlation study in selection programme is appreciable when highly heritable characters are associated with important characters like yield. Moreover, for important complex characters like yield per plant direct selection is not much effective, since number of specific forces are involved in the expression of the yield potential of a genotype. Yield is polygenically controlled complex character affected by large number of components. Hence, knowledge of correlation between yield and component characters and among component characters themselves is essential for a rational and direct improvement in yield. The correlation along with path analysis would give a better appreciation of cause and effect relationship between pairs of characters. In the present study, the association (Panse and Sukhatme 1985) [7] of different yield characters and bacoside A content the interrelationships with one another was also investigated (Dewey and Lu 1959) [16].

Materials and Methods

The experiment was carried out in the experimental fields at the Indian Institute of Horticultural Research, ICAR-IIHR, Bengaluru, Karnataka at a latitude of 13°7´ N, longitude

72° 29´ E at an altitude of 890 meters above mean sea level. The experimental material consisted of fifty germplasm lines of Brahmi which are collected from all the different regions of India. The details of the germplasm and source of collection is given in Table 1. The experiment was laid out in Augmented Block Design with two checks and only checks were replicated. The area was divided into five blocks of 10×15 m size with fourteen beds in each block. The distance between each block was 0.04 m. Data has been recorded for yield and its attributes on five random plants from each genotype. Total Bacoside A content consists of Bacoside A3, Bacopaside-II, Jujubogenin, Bacopasaponin C components and Bacoside A content of the herbage was determined by simultaneous estimation of all four components through HPLC technique. Data were analysed for correlation as per method suggested by Panse and Sukhatme (1985) [7] and for path analysis as Wright (1921) [15] which was subsequently elaborated by Dewey and Lu (1959) [16].

Results and Discussion

In any crop improvement programme, knowledge on the association of characters is of significant importance since it contributes indirectly to the success of selection. Yield is considered to be a dependent variable on several sub components. In such cases, knowledge on nature of association between such characters is a great asset for plant breeders to formulate their breeding procedures. It has been suggested that yield might be more effectively increased simultaneously improving one or more yield components (Aruna *et al*., 2009) [1].

Correlation coefficient analysis

Phenotypic and genotypic coefficients among yield and its attributing characters are presented in Table 2 & 3. The correlation studies in the present investigation revealed that the dry herbage yield recorded positive and significant correlation with fresh herbage yield (0.975 P, 0.973 G) followed by number of primary branches per plant (0.970 P, 0.987 G). While the association was negative but highly significant with flower diameter (-0.301 P, -0.535 G) at phenotypic and genotypic levels. Similar trends have been reported in *Bacopa monnieri* wettst. (Vishnuvardhan *et al.*, 2010) [11], *Solanum nigrum* L. (Ravi *et al.*, 2013) [9], *Stevia rebaudiana* (Hastoy *et al.*, 2019) [2], *Piper longum* L (Joseph 2008) [3], in *Andrographis paniculata* Nees. (Manjesh *et al*., 2016) [6] at genotypic level.

However, there was a positive and non-significant correlation with leaf/stem ratio (0.155 P, 0.218 G), Bacoside A (0.152 P, 0.160 G), leaf length (0.134 P), Bacisode-A3 (0.081 P, 0.081 G), Bacopasaponin C (0.065 P, 0.064 G), Jujubogenin (0.063 P, 0.063 G), leaf width (0.020 P) at phenotypic and genotypic levels. Bacoside A reported positive and significant correlation with Bacoside A3 (0.758 P, 0.757 G), Jujubogenin (0.707 P, 0.708 G), Bacopasaponin C (0.701 P, 0.700 G), Bacopaside-II (0.572 P, 0.570 G), leaf width (0.281 P, 0.330 G) with dry herbage yield at phenotypic and genotypic levels. Negative and significant correlation with the characters *viz*., Bacopasaponin C (0.065 P, 0.064 G), Jujubogenin (0.063 P, 0.063 G), Bacoside A3 (0.080 P, 0.081 G), leaf width (cm) (0.020 P, -0.098 G) and leaf length (cm) (-0.0478 P) showed negligible effect on dry herbage yield. The characters that showed negligible effect on herbage yield may not be taken into considerable in selection. The results show that yield and Bacoside content are not correlated hence there is greater scope for selection of genotypes with high herbage yield and high active ingredient.

Path coefficient analysis

Correlation coefficients indicate only the general association between any two traits without possible causes of such association. Path coefficient analysis a better idea of cause and effect relationship among different characters and plays an important role in determining the degree of relationship between yield and yield components. Therefore, the Path coefficient analysis was performed to partition the correlation into direct and indirect effect of different characters on yield.

The data pertaining to path coefficient analysis are presented in Table 4 & 5. The Path coefficient analysis based on dry herbage yield as a dependent variable revealed that Bacoside A (1.591 P, 0.485 G) had the higher positive direct effect on yield followed by fresh herbage yield (0.754 P, 0.969 G), number of primary branches per plant (0.213 P, 3.771 G) at phenotypic and genotypic level. Further, Bacisode-A3 (-0.628 P, -0.251 G), Bacopaside-II (-0.810 P, -0.207 G) Jujubogenin (-0.363 P, -0.024 G), Bacopasaponin C (-0.501 P, -0.157 G), leaf width (-0.052 P, -0.073 G) exhibited negative and direct effect on dry herbage yield at phenotypic and genotypic level. These traits had maximum significant and positive correlation with yield, direct selection for these traits should be done to improve yield of Brahmi.

These findings were in conformity with the (Srivastava *et al*., 2018) [14], (Patel *et al*., 2017) [8] in *Withania somnifera* (L.), (Singh *et al*., 2021) [12] in *Papaver somniferum* (L.) in seed, (Singh *et al*., 2017) [13] in *Catharanthus roseus* (L.) in leaves, (Ravi *et al*., 2018) [10] in *Mucuna pruriens* (L.) In pods.

Table 1: Germplasm lines of Brahmi used in the study

Sl. No.	Genotypes	Place of collection
1.	IIHR BM-2	Moothakunnum, Kerala
2.	IIHR BM-3	Kottuvalikodu, Kerala
3.	IIHR BM-4	Satara island, Kerala
4.	IIHR BM-5	Kasbara, West Bengal
5.	IIHR BM-6	Jamatala, West Bengal
6.	IIHR BM-8	Shyamnagar, West Bengal
7.	IIHR BM-9	Bansberia, West Bengal
8.	IIHR BM-13	Ramanthpur, West Bengal
9.	IIHR BM-15	Hessarghata lake, Karnataka
10.	IIHR BM-16	Ivarkandapura, Karnataka
11.	IIHR BM-17	Hessarghata, Karnataka
11.	IIHR BM-17	Hessarghata, Karnataka
12.	IIHR BM-18	Biljaji, Karnataka

13.	IIHR BM-19	Hessarghata lake, Karnataka
14.	IIHR BM -20	Hessarghata lake, Karnataka
15.	IIHR BM-21	Haniyur, Karnataka
16.	IIHR BM-23	Thippapura, Karnataka
17.	IIHR BM-27	NBPGR, Thrissur
18.	IIHR BM-28	NBPGR, Thrissur
19.	IIHR BM-29	NBPGR, Thrissur
20.	IIHR BM-30	NBPGR, Thrissur
21.	IIHR BM-31	NBPGR, Thrissur
22.	IIHR BM-33	NBPGR, Thrissur
23.	IIHR BM-35	NBPGR, Thrissur
24.	IC 249250	NBPGR, Thrissur
25.	IC 284992	NBPGR, Thrissur
26.	IC 321278	NBPGR, Thrissur
27.	IC 324774	NBPGR, Thrissur
28.	IC 324777	NBPGR, Thrissur
29.	IC 343108	NBPGR, Thrissur
30.	IC 353203	NBPGR, Thrissur
31.	IC 353204	NBPGR, Thrissur
32.	IC 370640	NBPGR, Thrissur
33.	IC 375976	NBPGR, Thrissur
34.	IC 392242	NBPGR, Thrissur
35.	IC 392842	NBPGR, Thrissur
36.	IC 426442	NBPGR, Thrissur
37.	IC 426447	NBPGR, Thrissur
38.	IC 439118	NBPGR, Thrissur
39.	IC 468878	NBPGR, Thrissur
40.	IC 554535	NBPGR, Thrissur
41.	IC 554585	NBPGR, Thrissur
42.	IC 554586	NBPGR, Thrissur
43.	IC 554587	NBPGR, Thrissur
44.	IC 554588	NBPGR, Thrissur
45.	IC 565466	NBPGR, Thrissur
46.	IC 565499	NBPGR, Thrissur
47.	IC 565503	NBPGR, Thrissur
48.	IC 565508	NBPGR, Thrissur
49.	JU2O/34	NBPGR, Thrissur
50.	JU26/32	NBPGR, Thrissur
51.	Check 1	Hesaraghatta, Karnataka
52.	Check 2	Agrahara, Karnataka

Table 2: Phenotypic correlation coefficients among different traits in Brahmi genotypes

Character	PB	LL	LW	FD	FW	L/S	B-A3	B-II	JB	BS	B-A	DW
PB	1.000	0.142	0.037	-0.277**	0.994**	0.063	0.070	0.131	-0.000	0.010	0.097	0.970**
LL		1.000	0.709**	0.150	0.139	0.082	-0.172	0.458**	-0.178	0.065	0.155	0.134
LW			1.000	-0.021	0.061	0.072	0.164	0.403	-0.010	0.035	0.281*	0.020
FD				1.000	-0.312*	-0.116	-0.128	0.008	-0.054	-0.094	-0.083	-0.301*
FW					1.000	0.092	0.086	0.145	0.013	0.017	0.117	0.975**
L/S						1.000	0.104	0.027	0.149	0.228	0.164	0.155
B-A3							1.000	0.098	0.749**	0.444**	0.758**	0.080
B-II								1.000	-0.096	0.082	0.572**	0.156
JB									1.000	0.644**	0.707**	0.063
BS										1.000	0.701**	0.065
B-A											1.000	0.152
DW												1.000

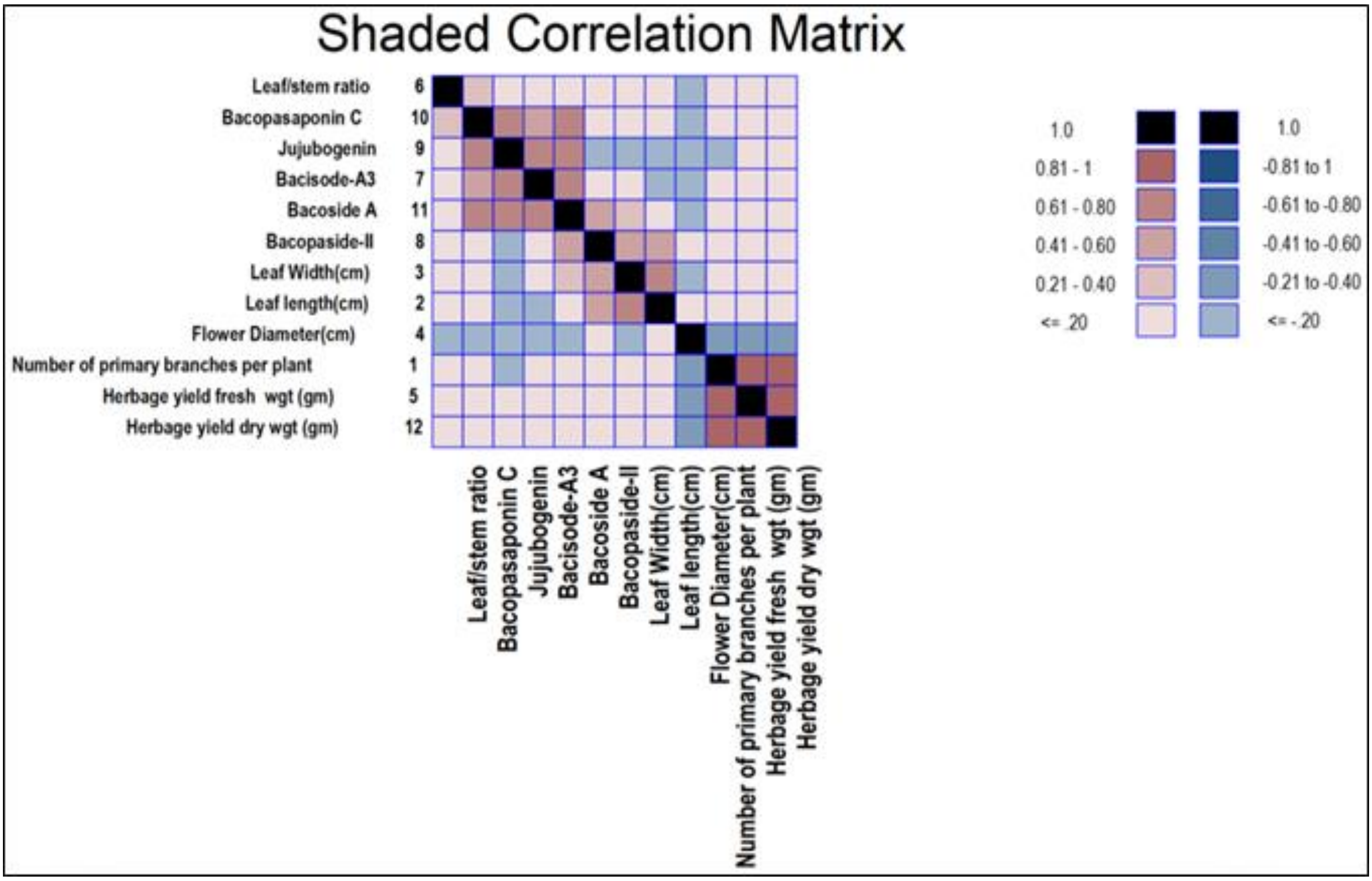

Fig 1: Shaded correlation matrix at phenotypic level in Brahmi genotypes

Table 3: Genotypic correlation coefficients among different traits in Brahmi

Character	PB	LL	LW	FD	FW	L/S	B-A3	B-II	JB	BS	B-A	DW
PB	1.000	-0.197	-0.159	-0.606**	0.824**	0.188	0.082	0.152	-0.004	0.015	0.121	0.987**
LL		1.000	0.670**	-0.055	-0.070	0.320*	-0.201	0.602**	-0.222	0.107	0.232	-0.047
LW			1.000	-0.172	-0.061	0.154	0.189	0.458**	-0.010	0.048	0.330*	-0.098
FD				1.000	-0.579**	-0.141	-0.155	0.003	-0.074	-0.121	-0.100	-0.535**
FW					1.000	0.158	0.089	0.153	0.008	0.014	0.126	0.973**
L/S						1.000	0.096	0.015	0.152	0.220	0.155	0.218
B-A3							1.000	0.095	0.749**	0.441*	0.757**	0.081
B-II								1.000	-0.098	0.078	0.570**	0.162
JB									1.000	0.644**	0.708**	0.063
BS										1.000	0.700**	0.064
B-A											1.000	0.160
DW												1.000

*Significant at 5 percent level; **significant at 1 percent level.
PB-No. of primary branches/plant, LL-Leaf length (cm), LW-Leaf width (cm), FD-Flower Diameter (cm), FW-Fresh herbage yield (gm/plot), L/S-Leaf/stem ratio, B-A3-Bacoside-Bacoside A3, B-II- Bacopaside-II, JB-Jujubogenin, BS-Bacopasaponin C, B-A-Bacoside-A, DW-Dry herbage yield (gm/plot)

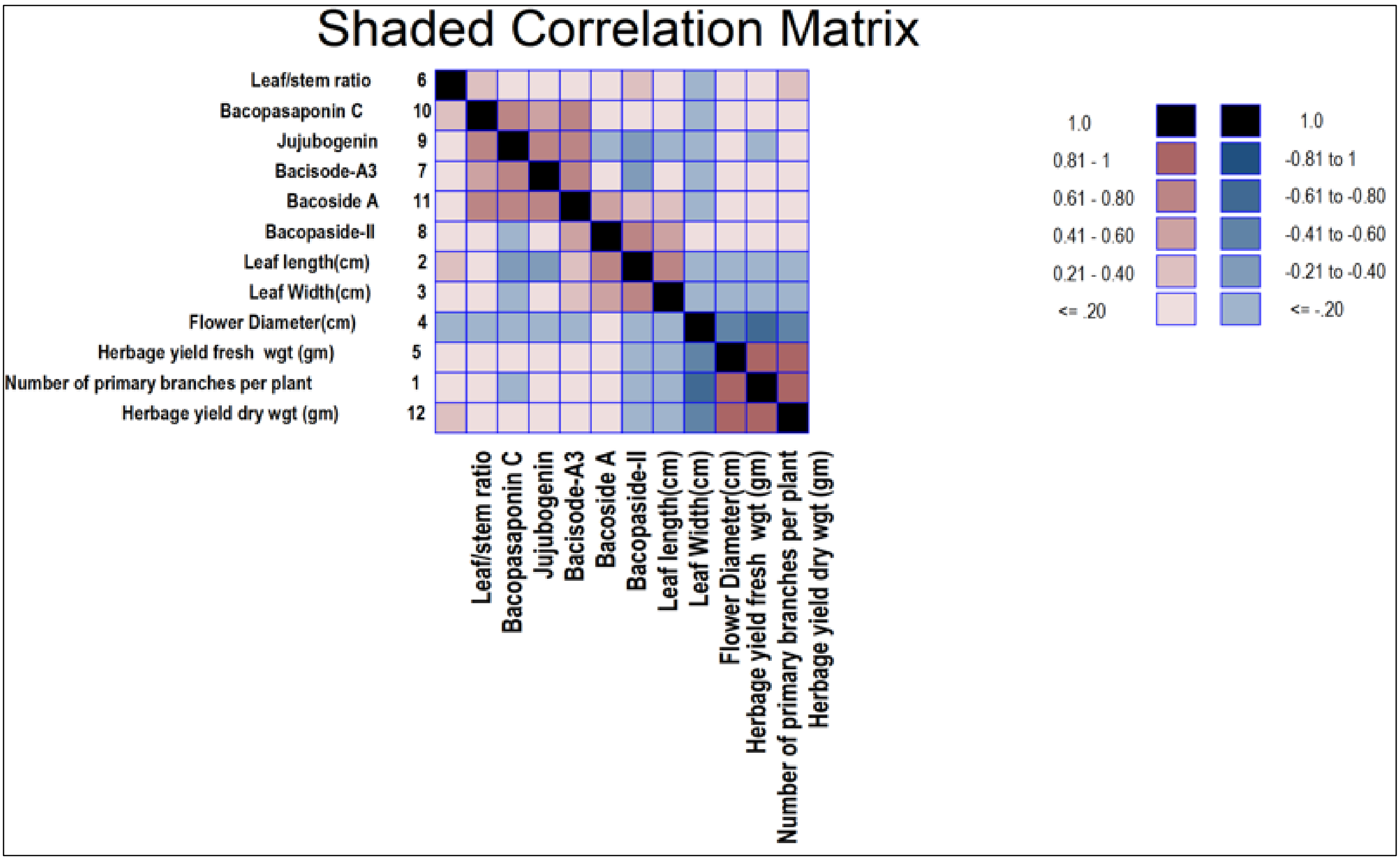

Fig 2: Shaded correlation matrix at genotypic level Brahmi genotypes

Table 4: Phenotypic path coefficient analysis showing direct and indirect effect on herbage yield in Brahmi genotypes

Character	PB	LL	LW	FD	FW	L/S	B-A3	B-II	JB	BS	B-A	DW	RP for dry herbage yield
PB	-0.213	0.030	0.008	-0.059	0.211	0.013	0.015	0.027	-0.000	0.002	0.020	0.970**	0.206
LL	0.002	0.014	0.01	0.002	0.002	0.001	-0.002	0.006	-0.002	0.000	0.002	0.134	0.001
LW	-0.002	-0.037	-0.052	0.001	-0.003	-0.003	-0.008	-0.021	0.000	-0.001	-0.014	0.020	-0.001
FD	0.002	-0.001	0.000	-0.008	0.002	0.001	0.001	-0.000	0.000	0.000	0.000	-0.301**	0.002
FW	0.749	-0.105	0.046	-0.235	0.754	0.069	0.065	0.11	0.009	0.013	0.088	0.975**	0.735
L/S	0.004	0.005	0.005	-0.008	0.006	0.070	0.007	0.001	0.010	0.016	0.011	0.155	0.010
B-A3	-0.044	0.108	-0.103	0.080	-0.054	-0.065	-0.628	-0.061	-0.471	-0.278	-0.476	0.080	-0.050
B-II	-0.106	-0.371	-0.326	-0.007	-0.118	-0.022	-0.079	-0.810	0.078	-0.066	-0.463	0.156	-0.127
JB	0.000	0.064	0.003	0.019	-0.004	-0.054	-0.272	0.035	-0.363	-0.234	-0.257	0.063	-0.023
BS	-0.005	-0.032	-0.017	0.047	-0.008	-0.114	-0.222	-0.041	-0.323	-0.501	-0.351	0.065	-0.032
B-A	0.155	0.247	0.446	-0.133	0.187	0.261	1.206	0.910	1.125	1.115	1.591	0.152	0.241
DW	0.970**	0.134	0.020	-0.301**	0.975**	0.155	0.080	0.156	0.063	0.065	0.152	1	

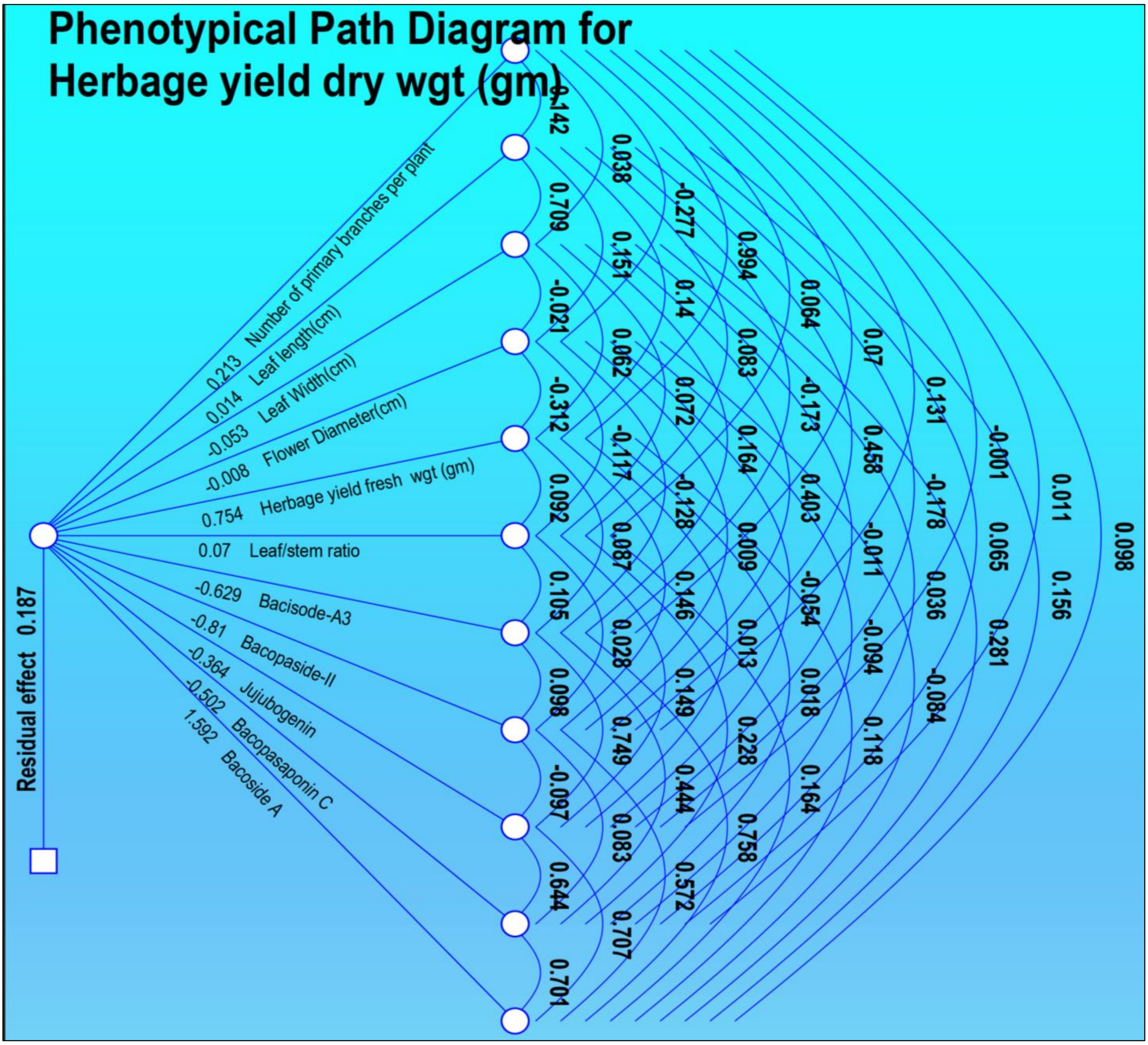

Fig 3: Path diagram for yield per plant (gm) at phenotypic level in Brahmi genotypes

Table 5: Genotypic path coefficient analysis showing direct and indirect effect on herbage yield in Brahmi genotypes

Character	PB	LL	LW	FD	FW	L/S	B-A3	B-II	JB	BS	B-A	DW	rg for dry herbage yield
PB	-0.010	0.002	0.001	0.006	-0.010	-0.001	-0.000	-0.001	0.000	-0.000	-0.001	0.987**	-0.010
LL	-0.004	0.020	0.014	-0.001	-0.001	0.006	-0.004	0.012	-0.004	0.002	0.004	-0.047	-0.001
LW	0.011	-0.049	-0.073	0.012	0.004	-0.011	-0.014	-0.033	0.008	-0.003	-0.024	-0.098	0.007
FD	-0.004	-0.000	-0.001	0.006	-0.003	-0.001	-0.001	0.000	-0.000	-0.000	-0.000	-0.535**	-0.003
FW	0.977	-0.068	-0.059	-0.561	0.969	0.153	0.087	0.148	0.008	0.014	0.122	0.973**	0.942
L/S	0.011	0.020	0.009	-0.009	0.01	0.063	0.006	0.001	0.009	0.014	0.009	0.218	0.013
B-A3	-0.020	0.050	-0.047	0.039	-0.022	-0.024	-0.251	-0.023	-0.188	-0.110	-0.190	0.081	-0.020
B-II	-0.031	-0.124	-0.094	-0.000	-0.031	-0.003	-0.019	-0.207	0.020	-0.016	-0.118	0.162	-0.033
JB	0.000	0.005	0.000	0.001	-0.000	-0.003	-0.018	0.002	-0.024	-0.016	-0.017	0.063	-0.001
BS	-0.002	-0.017	-0.007	0.019	-0.002	-0.034	-0.069	-0.012	-0.101	-0.157	-0.110	0.064	-0.010
B-A	0.058	0.112	0.160	-0.048	0.061	0.075	0.367	0.276	0.343	0.339	0.485	0.160	0.077
DW	0.987**	0.047	-0.098	-0.535**	0.973**	0.218	0.081	0.162	0.063	0.064	0.160	1	

Phenotypic Residual effect = 0.187, Genotypic Residual effect = 0.197.

Rp: Phenotypic correlation coefficient Rg: Genotypic correlation coefficient.

*Significant at 5 percent level; **Significant at 1 percent level, Diagonal bold values indicate direct effects.

PB-No. of primary branches/plant, LL-Leaf length (cm), LW-Leaf width (cm), FD-Flower Diameter (cm), FW-Fresh herbage yield (gm/plot), L/S- Leaf /stem ratio, B-A3-Bacoside-Bacoside A3, B-II- Bacopaside-II, JB-Jujubogenin, BS-Bacopasaponin C, B-A-Bacoside-A, DW-Dry herbage yield (gm/plot).

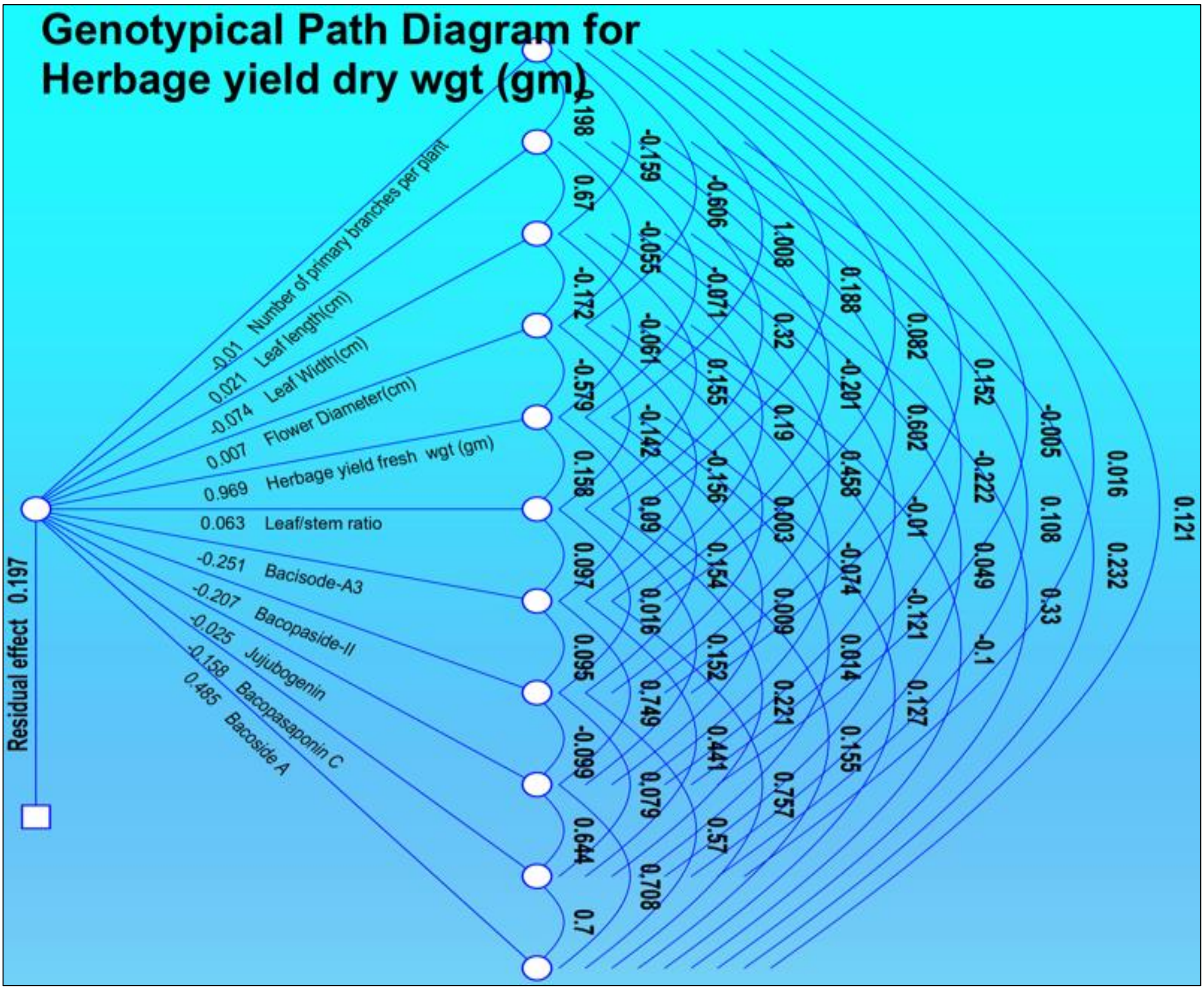

Fig 4: Path diagram for yield per plant (gm) at genotypic level in Brahmi genotypes

Conclusion
In conclusion, the results of correlation and path coefficient analysis clearly indicate dry herbage yield per plot exhibited positive and significant association with number of primary branches per plant and fresh herbage yield at genotypic and phenotypic level. Bacoside A had the higher positive direct effect on yield followed by fresh herbage yield, number of primary branches per plant at phenotypic and genotypic level. Thus, the present study suggests that all these traits should be considered simultaneously in selection programme aimed at improving of Brahmi genotypes with higher yields.

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Conflict of interest
The authors declare no conflict of interest.

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