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Research Article

Genetic variability, heritability, correlation and path analysis in *seenthil kodi* (*Tinospora cordifolia*)

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Abstract
India has a vast range of medicinal plants at its disposal. *Tinospora cordifolia*, often known as „Seenthil Kodi“ , is a dioecious hanging shrub, proven to be a valuable botanical for herbal medicine, with an extensive array of bioactive components. The goal of the current research was to determine the ideal lines with high stem yield and also the assess genetic diversity, heritability, genetic advance and trait association in the crop. During 2021–2022, 48 genotypes were examined for 16 characters in CRBD. Higher PCV, GCV, heritability and GAM, according to studies on variability, indicate lesser environmental impact. According to correlation analysis, leaf fresh weight, leaf dry weight, stem fresh weight, stem dry weight, root fresh weight, root dry weight, whole plant fresh weight and whole plant dry weight were very significant and strongly connected with single plant yield. The path analysis revealed that the yield is directly and positively impacted by the stem yield. Thus, selection based on the fresh leaf weight and stem weight would aid in boosting whole plant weight.

Keywords: *Tinospora cordifolia;* GCV; PCV; Correlation; Path analysis

INTRODUCTION

India has a vast range of medicinal plants at its disposal. One of the important plants, though less exploited, is *Tinospora cordifolia* (Willd) Miers ex Hook. F. & Thoms. It is vernacularly known as *Seenthil kodi* and belongs to the family Menispermaceae (Stanely *et al*., 2000). Although it has been demonstrated that *Tinospora* is a useful plant for herbal medicine and possesses a wide range of bioactive components, it has not garnered much attention from scientists. It is known as Guduchi in Sanskrit, which translates as „the one who protects the body,“ as it is so effective at boosting the body‘s immune system. Native to India, seenthil kodi is found in both dry and deciduous forests. Furthermore, it can be encountered in Burma, Thailand, Malaysia, Sri Lanka, Bangladesh, and Pakistan, as well as in the regions of Kangra, Una, Chamba, Hamirpur, and Mandi within Himachal Pradesh (Chauhan, 1999). It is a perennial dioecious twiner with papery skin and a succulent stem. *Seenthil kodi* typically grows naturally in forests and other places. The plant sends out aerial roots that can reach a length of 30 feet as it spirals up large trees and clings to them, occasionally even electrical poles. Stem cuttings are the main method of vegetative propagation used for this crop (Akhilraj *et al*., 2023). The plant thrives in a variety of soils, from acidic to alkaline, with moderate rainfall and medium to full light. Inflorescence are axillary racemes of yellow flowers with long stalks .The drupes are ovoid, glossy, succulent, red and pea sized. The seeds are curved. Fruits are fleshy and single seeded. The plant blooms in June, and during November it bears fruit (Chaudhari and Shaikh , 2013).

T. cordifolia has been widely used in traditional Ayurvedic medicine for its therapeutic properties. It is known for its immunomodulatory, antioxidant, anti-inflammatory, and antimicrobial properties. The plant is used to treat various ailments such as fever, respiratory disorders, liver disorders, diabetes, arthritis, and skin diseases (Sharma *et al.,* 2010). The demand for *T. cordifolia* in the herbal medicine industry has contributed to its economic value. Extracts and formulations derived from this medicinal plant are used in the production of herbal and nutraceutical products. The products, ranging from capsules, tablets, syrups, and powders, are marketed as immune boosters, health supplements, and natural remedies for various health conditions. The commercialization of *T. cordifolia* based products has created market demand and economic opportunities (Spandana *et al*., 2013).

Plant breeders work to create cultivars with more productive traits and other targeted agronomic traits. Breeders have the option of delaying strong selection until subsequent generations or picking desirable genotypes in the early generations. Breeding efforts for development of high yield crop varieties requires information regarding the type and extent of variability present in the available materials, the correlation between yield and other agronomic attributes, and the influence of the environment on the behavior of these constituent traits. (Sathish Kumar *et al*., 2022). Yield is a complicated polygenic variable. Since direct selection is heavily impacted by external influences, it would not be a trustworthy method. Path analysis aids in identifying qualities that have direct effects on yield as well as indirect effects on other characteristics. The germplasm acts as a valuable source of significant variation. In the present study, the genetic variability, heritability, correlation, and path analysis among yield and related characteristics were evaluated using 48 *T. cordifolia* germplasms.

MATERIALS AND METHODS

Plant collection: The present research was carried out during 2022 at the Horticultural College and Research Institute, TNAU, Coimbatore, in the field of medicinal and aromatic crops. The experiment location, which is in the Western Zone of Tamil Nadu, received 943 mm of precipitation in 2022. A total of 48 *seenthil kodi* germplasm that had been gathered from different regions of Tamil Nadu during 2021–2022 (**Table 1**) were chosen for this study based on morphological variability. For the purpose of interpreting genetic variation biometric characteristics including plant height (cm), main stem thickness (cm), petiole length (cm), leaf lamina length (cm), leaf length (cm), leaf breadth (cm), internodal length (cm), fresh leaf weight (g), dry leaf weight (g), fresh stem weight (g), dry stem weight (g), fresh root weight (g), dry root weight (g), whole plant fresh weight (g) and whole plant dry weight (g) were recorded. Collected populations were established in Medicinal plants departmental garden in CRBD with three replications. The spacing followed was 2 m x 3 m and cultural practices were done accordingly. The data pertaining to the above traits were collected from five randomly chosen plants in each replication. The mean of the observations recorded were analysed for genotypic and phenotypic coefficients of variation (Sivasubramanian and Madhavamenon, 1973), heritability (Lush, 1940), genetic advance (Johnson *et al*., 1955a), correlation and path analysis were analyzed employing the methods proposed by Johnson *et al*. (1955b); Dewey and Lu (1959) respectively. The GRAPES programme was used for the statistical analysis (Gopinath *et al*., 2020).

RESULTS AND DISCUSSION

Tinospora cultivars were subjected to genetic variability studies and the values were statistically significant. All of the quantitative features had significant differences according to the ANOVA (**Tables 2 and 3**), which indicated a high degree of genetic diversity. For 16 quantitative features, the average score of 48 genotypes demonstrated a clear variance in *T. cordifolia*. The significant genotypic mean squares for each of the traits indicate presence of ample variability among the genotypes. The genotype TC-23 recorded the highest petiole length (8.41 cm), leaf length (18.95 cm) and leaf width (11.89 cm). The average petiole length of *T. cordifolia* genotype collected from the northwest Himalayan region of India has been reported to be 7.61 cm with a range of 5.15 cm to 10.37 cm (Rana,2012) . Thakur *et al*. (2020) observed that the *Tinospora* species had a leaf length of 4.81 cm, leaf width of 5.67 cm, and petiole length of 4.28 cm. Similarly, Abhijeet and Mokat (2018) reported in vegetatively propagated *Tinospora* species using stem cuttings, the petiole length was 3.71 cm, leaf length was 4.49 cm, and leaf width was 3.97 cm.

In the current study, TC-35 genotype, recorded the maximum leaf lamina length (10.6 cm), the internodal length (10.71 cm) and the plant height 515.96 cm. Joy *et al.* (2012) conducted a microscopic evaluation of *T. cordifolia* and *T. malabarica*, the two botanical sources of *seenthil kodi*, and reported an average internode length of 7.17 cm for *T. cordifolia*. The internode length for *T. malabarica* is typically 5 cm. According to observations by Devi *et al.* (2015) at 200 days after planting, the average plant length showed significant variation, ranging from 125.33 cm to 190.33 cm. The North Western Himalaya Collection-11 recorded the longest plants at 190.33 cm, while Collection-8 recorded the shortest plants at 125.33 cm.

The accession TC-08 was observed to register the maximum main stem thickness (5.22 cm,) leaf fresh weight per plant (903.92 g), the leaf dry weight per plant (184.69 g), stem fresh weight per plant (6136.96 g), stem dry weight per plant (629.94 g), root fresh weight per plant (189.95 g), root dry weight per plant (30.90 g), whole plant fresh weight (7230.84 g) and the whole plant dry weight (845.54 g) with early flowering (117.91 days) nature. Gufran *et al*. (2015) examined *T. cordifolia* populations

Table 1. Genotype of *T. cordifolia* assembled from several sites in Tamil Nadu

Accession	Place	District	Latitude	Longitude	Altitude (MSL)
TC-01	Dharmathupatti	Theni	9°59'38"N	77°20'56"E	351 m
TC-02	Narasingapuram	Theni	9°56'18"N	77°36'01"E	341 m
TC-03	Palani	Dindigul	10°26'57"N	77°30'58"E	378 m
TC-04	Villacheri	Madurai	9°53'45"N	78°03'39"E	143 m
TC-05	Srivilliputhur	Virudhunagar	9°30'25"N	77°38'02"E	150 m
TC-06	Thalaivasal	Salem	11°35'10"N	78°45'30"E	162 m
TC-07	Thantheeni	Karur	10°55'50"N	78°05'49"E	131 m
TC-08	Samathuvapuram	Salem	11°49'32"N	77°55'09"E	360 m
TC-09	Kaveripattinam	Krishnagiri	12°25'05"N	78°13'05"E	464 m
TC-10	Nallampalli	Dharmapuri	12°03'33"N	78°06'49"E	485 m
TC-11	Papparapatti	Dharmapuri	12°12'25"N	78°03'26"E	494 m
TC-12	Perundurai	Erode	11°16'15"N	77°34'57"E	278 m
TC-13	Natrampalli	Thirupathur	12°35'07"N	78°30'29"E	443 m
TC-14	Kalavai	Ranipet	12°46'01"N	79°25'01"E	132 m
TC-15	Sendamangalam	Namakkal	11°16'51"N	78°14'15"E	180 m
TC-16	Somandargudi	Kallakurichi	11°45'36"N	78°55'56"E	135 m
TC-17	Cheyyar	Thiruvannamalai	12°39'12"N	79°32'39"E	90 m
TC-18	Thiruvetriyur	Ramanathapuram	9°42'29"N	78°57'02"E	11 m
TC-19	Gopalasamudram	Thirunelveli	8°40'22"N	77°37'49"E	55 m
TC-20	Thovalai	Kanyakumari	8°13'47"N	77°30'02"E	49 m
TC-21	Thally	Krishnagiri	12°35'09"N	77°39'09"E	910 m
TC-22	Nemili	Ranipet	12°36'07"N	78°31'00"E	435 m
TC-23	Gudiyatham	Vellore	12°56'12"N	78°52'46"E	268 m
TC-24	Pallikonda	Vellore	12°54'22"N	78°56'17"E	251 m
TC-25	Ashok Nagar	Chennai	13°02'09"N	80°12'43"E	10 m
TC-26	Virudhachalam	Cuddalore	11°30'52"N	79°19'31"E	33 m
TC-27	Neyveli	Cuddalore	11°32'07"N	79°28'46"E	35 m
TC-28	Kalpakkam	Kanchipuram	12°31'19"N	80°09'26"E	2 m
TC-29	Padappai	Kanchipuram	12°52'43"N	80°01'50"E	28 m
TC-30	Acharavakkam	Chengalpattu	12°41'44"N	79°58'41"E	32 m
TC-31	Pallipattu	Thiruvallur	13°19'59"N	79°26'34"E	158 m
TC-32	Vanthavasi	Thiruvannamalai	12°29'58"N	79°35'56"E	71 m
TC-33	Tindivanam	Villupuram	12°13'21"N	79°38'44"E	37 m
TC-34	Palaiyur	Mayiladuthurai	10°46'28"N	79°49'01"E	4 m
TC-35	Courtallam	Tenkasi	8°55'27"N	77°16'40"E	194 m
TC-36	Thirupuvanam	Sivagangai	9°49'25"N	78°15'15"E	106 m
TC-37	Thirukalukundram	Chengalpattu	12°36'18"N	80°03'50"E	33 m
TC-38	Mathampatti	Coimbatore	10°58'11"N	76°51'33"E	428 m
TC-39	Saravanampatti	Coimbatore	11°04'36"N	77°00'02"E	418 m
TC-40	Kinethukadavu	Coimbatore	10°48'39"N	77°01'20"E	308 m
TC-41	Kunnathur	Thirupur	11°15'43"N	77°25'01"E	313 m
TC-42	Kannaivadi	Thirupur	10°48'40"N	77°47'04"E	201 m
TC-43	Bhavanisagar	Erode	11°28'37"N	77°08'13"E	257 m
TC-44	Nilakottai	Dindigul	10°09'51"N	77°51'08"E	226 m
TC-45	Vedasandur	Dindigul	10°31'50"N	77°56'54"E	212 m
TC-46	Kallupatti	Madurai	9°43'04"N	77°51'13"E	142 m
TC-47	Karaiyipatti	Madurai	10°06'52"N	78°26'21"E	129 m
TC-48	Mohanur	Namakkal	11°03'18"N	78°08'39"E	117 m

Table 2. Morphological characters of collected accessions of *Tinospora cordifolia*

Collected Accession	Petiole length (cm)	Leaf lamina length (cm)	Leaf length (cm)	Leaf width (cm)	Internodal length (cm)	Days to flowering	Main stem thickness (cm)	Plant height (cm)
TC-01	5.66	8.28	13.94	9.53	4.37	136.52	3.56	380.13
TC-02	6.53	8.47	15.00	8.06	5.73	130.35	2.95	307.16
TC-03	6.96	8.8	15.77	9.19	5.92	144.75	3.04	358.1
TC-04	5.83	9.16	15.00	9.12	8.59	152.46	3.56	359.87
TC-05	5.75	8.78	14.53	8.18	4.46	152.75	3.37	395.98
TC-06	4.85	8.89	13.75	9.76	8.72	161.24	4.3	370.48
TC-07	7.48	9.29	16.77	9.74	4.95	130.78	4.07	309.39
TC-08	8.03	10.26	18.29	11.27	10.01	117.91	5.23	512.69
TC-09	7.42	9.43	16.85	9.99	6.5	137.32	4.26	303.63
TC-10	6.19	7.02	13.21	9.79	8.39	132.77	2.72	347.5
TC-11	5.22	9.16	14.38	9.53	5.16	130.19	4.03	314.72
TC-12	5.61	7.25	12.86	7.98	5.94	129.78	3.73	346.5
TC-13	6.83	7.67	14.5	8.13	4.49	132.28	3.11	313.86
TC-14	7.91	9.83	17.74	10.69	9.64	121.4	4.77	479.74
TC-15	6.90	8.05	14.95	9.38	7.96	140.55	3.8	328.46
TC-16	5.94	8.55	14.49	9.46	4.31	144.04	3.59	359
TC-17	6.49	8.76	15.25	9.00	6.95	138.56	3.18	309.79
TC-18	7.06	9.11	16.17	9.49	5.84	154.17	3.09	344.57
TC-19	7.44	8.87	16.3	9.08	8.43	153.7	3.63	471.81
TC-20	6.01	9.44	15.45	8.02	4.36	153.71	3.37	397.04
TC-21	4.75	8.38	13.13	9.77	8.32	160.36	2.49	379.81
TC-22	6.38	8.87	15.25	8.88	6.84	130.01	3.69	327.89
TC-23	8.41	10.55	18.96	12.01	9.94	123.79	4.94	494.46
TC-24	6.89	8.21	15.11	10.44	5.64	145.96	3.58	322.25
TC-25	6.04	6.99	13.03	9.49	7.67	130.06	2.86	332.88
TC-26	5.12	9.13	14.25	8.71	5.2	147.92	4.17	354.06
TC-27	7.91	9.58	17.49	10.84	10.66	126.97	4.51	512.07
TC-28	6.59	8.65	15.24	7.84	4.55	133.57	3.09	313.82
TC-29	7.52	8.73	16.25	7.89	6.49	169.28	3.94	417.01
TC-30	7.72	8.74	16.46	9.24	5.04	136.66	4.09	428.23
TC-31	5.89	8.99	14.88	9.46	4.21	144.73	3.65	350.28
TC-32	6.23	9.38	15.62	9.04	6.55	145.64	2.87	327.86
TC-33	7.02	8.29	15.31	9.18	5.8	153.4	3.14	351.78
TC-34	7.50	9.06	16.56	9.27	6.97	142.95	3.53	386.43
TC-35	8.22	10.6	18.82	11.28	10.71	125.72	5.15	515.96
TC-36	4.78	8.52	13.3	9.37	8.25	162.34	2.65	377.36
TC-37	6.48	7.00	13.48	8.71	5.58	134.49	3.59	319.13
TC-38	7.15	8.92	16.07	8.4	6.45	132.5	3.64	285.59
TC-39	6.82	7.07	13.89	10.19	6.68	147.45	4.23	316.83
TC-40	5.99	9.12	15.11	9.78	9.18	130.86	2.84	355.17
TC-41	5.00	8.41	13.41	10.32	5.17	136.24	4.06	325.72
TC-42	5.75	9.09	14.84	8.12	5.63	131.63	3.82	350.53
TC-43	7.01	9.4	16.41	8.01	4.5	130.53	3.09	309.2
TC-44	7.54	9.27	16.81	9.94	6.67	169.54	4.15	411.19
TC-45	7.52	8.29	15.81	9.14	9.08	136.58	4.03	415.72
TC-46	5.71	8.82	14.53	8.65	7.39	157.41	2.48	345.74
TC-47	6.21	7.86	14.06	8.05	5.41	160.7	3.3	350.51
TC-48	5.54	8.65	14.19	7.85	6.48	143.11	3.77	388.19
SE(d)	**0.149**	**0.116**	**0.197**	**0.122**	**0.091**	**2.182**	**0.215**	**4.930**
C.D.	**0.295**	**0.231**	**0.391**	**0.243**	**0.18**	**4.332**	**0.427**	**9.788**
CV	**2.785**	**1.629**	**1.580**	**1.614**	**1.66**	**1.890**	**7.278**	**1.639**

Table 3. Yield characters of collected accessions of *Tinospora cordifolia*

Collected Accessions	LFW (g/p)	LDW (g/p)	SFW (g/p)	SDW (g/p)	RFW (g/p)	RDW (g)	WPFW (g/p)	WPDW (g/p)
TC-01	256.01	62.98	4834.69	366.72	74.82	12.4	5165.52	442.1
TC-02	416.58	83.52	3474.65	309.3	75.58	12.64	3966.81	405.46
TC-03	352.86	71.70	5716.34	238.16	83.78	13.95	6152.98	323.81
TC-04	286.09	80.50	2478.15	231.63	90.07	15.26	2854.31	327.4
TC-05	281.1	75.40	4421.66	399.03	145.87	24.04	4848.63	498.47
TC-06	612.12	130.04	3392.41	303.08	95.69	15.57	4100.22	448.69
TC-07	459.02	100.45	3301.89	293.9	111.79	18.82	3872.71	413.17
TC-08	903.93	184.69	6136.97	629.95	189.96	30.91	7230.85	845.55
TC-09	326.12	75.11	2452.35	224.67	117.43	19.84	2895.89	319.63
TC-10	535.45	105.14	3386.32	306.93	119.48	20.09	4041.25	432.17
TC-11	376.99	78.25	5012.45	456.85	90.27	15.36	5479.70	550.46
TC-12	203.66	55.20	2251.37	206.09	164.8	27.76	2619.83	289.05
TC-13	370.13	76.78	3018.28	273.16	83.14	16.26	3471.55	366.19
TC-14	807.12	140.79	6007.00	522.21	165.89	27.84	6980.00	690.84
TC-15	182.31	56.05	3540.31	317.94	73.63	12.27	3796.24	386.26
TC-16	254.99	63.21	2489.46	227.02	71.41	12.22	2815.86	302.45
TC-17	398.57	87.45	4357.84	392.28	87.8	14.47	4844.21	494.19
TC-18	359.12	70.49	3274.95	298.91	88.15	15.09	3722.23	384.49
TC-19	285.8	82.02	3218.32	291.92	145.04	23.79	3649.16	397.73
TC-20	287.99	75.15	4078.83	378.01	93.99	15.87	4460.81	469.02
TC-21	616.68	136.13	2438.87	224.96	116.06	19.10	3171.61	380.19
TC-22	452.5	99.48	3480.11	310.78	145.47	23.89	4078.08	434.16
TC-23	874.52	181.50	5980.02	461.96	168.57	28.52	7023.11	671.97
TC-24	326.93	74.55	2179.5	196.05	116.27	18.88	2622.7	289.49
TC-25	547.96	107.75	3069.18	293.55	91.41	15.39	3708.54	416.69
TC-26	374.85	78.38	3510.87	317.55	126.25	20.97	4011.97	416.9
TC-27	752.77	143.70	5868.07	525.59	165.59	28.20	6786.43	697.49
TC-28	259.89	61.77	2510.16	229.6	76.63	12.59	2846.68	303.96
TC-29	419.54	81.11	4445.67	404.89	88.39	14.84	4953.59	500.84
TC-30	350.99	70.99	3405.3	314.25	88.52	14.76	3844.8	400
TC-31	276.67	79.51	3216.62	301.95	144.06	24.13	3637.35	405.59
TC-32	285.97	72.98	4193.45	382.26	95.8	16.09	4575.22	471.34
TC-33	608.31	124.12	2405.73	216.64	113.25	18.96	3127.28	359.72
TC-34	474.07	98.79	3238.98	293.34	153.4	25.89	3866.45	418.02
TC-35	867.9	173.74	5896.17	561.12	179.05	30.07	6943.12	764.93
TC-36	309.89	75.7	2236.43	205.9	169.98	27.78	2716.31	309.37
TC-37	520.63	104.12	4507.53	427.6	91.08	15.22	5119.24	546.94
TC-38	375.05	78.3	4465.62	409.7	111.47	18.69	4952.13	506.68
TC-39	193.98	55.93	3343.11	301.62	78.26	12.81	3615.34	370.36
TC-40	245.96	62.17	3213.76	285.05	78.83	13.05	3538.55	360.27
TC-41	415.32	83.02	4130.48	376.66	83.86	13.99	4629.66	473.68
TC-42	360.14	75.15	2449.74	219.9	86.87	14.29	2896.75	309.34
TC-43	268.48	79.9	3447.79	313.72	140.47	23.49	3856.74	417.11
TC-44	279.54	74.68	4869.96	438.85	91.53	15.59	5241.04	529.12
TC-45	595.79	141.48	2190.73	200.00	111.15	18.71	2897.67	360.19
TC-46	450.3	101.86	5656.45	391.11	124.15	20.65	6230.9	513.62
TC-47	321.5	71.87	3508.53	327.99	115.67	19.61	3945.7	419.47
TC-48	538.4	113.47	5123.38	382.6	146.33	24.45	5808.1	520.52
SE(d)	**5.605**	**1.180**	**54.251**	**4.642**	**1.733**	**0.283**	**55.406**	**4.666**
C.D.	**11.129**	**2.343**	**107.716**	**9.218**	**3.441**	**0.561**	**110.010**	**9.265**
CV	**1.622**	**1.556**	**1.754**	**1.708**	**1.863**	**1.816**	**1.569**	**1.285**

(LFW-Leaf fresh weight per plant (g), LDW-Leaf dry weight per plant (g), SFW-Stem fresh weight per plant (g), SDW-Stem dry weight per plant (g), RFW-Root fresh weight per plant (g), RDW-Root dry weight per plant (g), WPFW-Whole plant fresh weight (g), WPDW-Whole plant dry weight (g))

from 15 different locations for variation, heredity, and character connections and reported root fresh weight to be 159.80 g, shoot fresh weight to be 4268.45 g, leaf fresh weight to be 629.03 g and total plant biomass to be 5057.28 g.

Variability: Genotypic coefficient of variation (GCV) , phenotypic coefficient of variation (GCV) , heritability in the broad sense and genetic advance as a percentage mean were all used to assess the nature of gene action of traits in *seenthil kodi* (**Table 4**). The PCV was slightly greater than the GCV which indicates that the environmental effect on expression of the traits was relatively less. PCV and GCV were higher for leaf fresh weight per plant (43.42 %, 43.39 %), leaf dry weight per plant (35.00 %, 34.97 %), stem fresh weight per plant (31.22 %, 31.17 %), stem dry weight per plant (30.26 %, 30.21 %), root fresh weight per plant (29.19 %, 29.13 %), root dry weight per plant (28.81 %, 28.75%), whole plant fresh weight (30.00 %, 29.96 %), whole plant dry weight (27.81 %, 27.78 %) providing an opportunity for additional improvement through selection (**Table 4**). Strong GCV and PCV levels suggested a high variation for choosing the best genotypes for these features. For the remaining characters, small differences between PCV and GCV suggested that they were relatively resistant to environmental variation, indicating that the expression of these traits were influenced by genetic effects and that selection could be done successfully based on phenotypic performance.

Heritability in combination with genetic advance helps to depict the genetic improvement under phenotypic selection. For all attributes, the estimated level of heritability in broad sense varied from 86.30 % for main stem thickness to 99.99 % for leaf fresh weight. The phenotypes were the accurate reflection of their genotypes, as indicated by the high broad sense heritability values, and choice based on quantitative performance would be trustworthy. A high degree of heritability (**Table 4**) was noted in the current study for traits such leaf fresh weight (99.90 %) followed by leaf dry weight (99.80 %), whole plant dry weight (99.80 %), whole plant fresh weight (99.70 %), stem fresh weight (99.70 %), stem dry weight (99.70 %), internodal length (99.60 %), root fresh weight (99.60 %), root dry weight (99.60 %), petiole length (99.60 %) similar results were reported by Gufran *et al.* (2015). The high heritability indicates the dominance of additive gene action in determining the traita. Genetic advance as percentage of mean was maximum for leaf fresh weight (89.32 %) followed by leaf dry weight (71.97 %), stem fresh weight (64.11 %), stem dry weight (62.14 %), whole plant fresh weight (61.63 %) and whole plant dry weight (57.17 %). Characters that have excellent heritability and GAM demonstrate the preponderance of additive gene action and may be improved by selection method of breeding. Low genetic advance combined with low heritability indicates that the trait is heavily influenced by environmental factors, and selection based on such traits may not be effective.

Table 4. Variability, heritability and genetic advance for yield parameters in *Tinospora* germplasm

	PCV (%)	GCV (%)	Heritability (%)	Genetic advance (%)
Petiole length	14.971	14.711	96.60	29.778
Leaf lamina length	9.573	9.435	97.10	19.157
Leaf length	9.892	9.765	97.50	19.860
Leaf width	10.462	10.340	97.70	21.050
Internodal length	27.499	27.450	99.60	56.447
DFI	9.165	8.968	95.70	18.077
MST	19.611	18.218	86.30	34.865
Plant height	16.291	16.208	99.00	33.219
LFW	43.422	43.392	99.90	89.325
LDW	35.008	34.973	99.80	71.974
SFW	31.222	31.172	99.70	64.114
SDW	30.265	30.217	99.70	62.147
RFW	29.195	29.135	99.60	59.896
RDW	28.811	28.754	99.60	59.115
WPFW	30.003	29.962	99.70	61.638
WPDW	27.815	27.785	99.80	57.177

(DFI- Days to flower Initiation, MST- Main Stem Thickness, LFW-Leaf fresh weight per plant (g), LDW-Leaf dry weight per plant (g), SFW-Stem fresh weight per plant (g), SDW-Stem dry weight per plant (g), RFW-Root fresh weight per plant (g), RDW-Root dry weight per plant (g), WPFW-Whole plant fresh weight (g), WPDW-Whole plant dry weight (g))

Table 5. Correlation coefficient between quantitative traits in *Tinospora*

	PTL	LLL	LL	LW	IL	DFI	MST	PH	LFW	LDW	SFW	SDW	RFW	RDW	WPFW	WPDW
PTL	1															
LLL	0.389**	1														
LL	0.86***	0.804***	1													
LW	0.38**	0.392**	0.462***	1												
IL	0.331*	0.319*	0.391**	0.612***	1											
DFI	-0.336*	-0.159	-0.304*	-0.292*	-0.18	1										
MST	0.501***	0.497***	0.598***	0.559***	0.346*	-0.357*	1									
PH	0.47***	0.534***	0.598***	0.512***	0.627***	-0.088	0.579***	1								
LFW	0.394**	0.396**	0.473***	0.573***	0.658***	-0.374**	0.491***	0.634***	1							
LDW	0.382**	0.435**	0.487***	0.583***	0.692***	-0.322*	0.489***	0.664***	0.971***	1						
SFW	0.336*	0.475***	0.48***	0.352*	0.315*	-0.242	0.432**	0.511***	0.506***	0.461***	1					
SDW	0.372**	0.491***	0.511***	0.397**	0.363*	-0.302*	0.558***	0.555***	0.56***	0.525***	0.889***	1				
RFW	0.265	0.418**	0.402**	0.33*	0.472***	-0.226	0.381**	0.594***	0.547***	0.599***	0.305*	0.378**	1			
RDW	0.283	0.415**	0.412**	0.324*	0.464***	-0.24	0.383**	0.593***	0.552***	0.601***	0.309*	0.382**	0.997***	1		
WPFW	0.369**	0.5***	0.515***	0.411**	0.392**	-0.28	0.473***	0.571***	0.617***	0.573***	0.991***	0.899***	0.381**	0.386**	1	
WPDW	0.415**	0.533***	0.562***	0.491***	0.498***	-0.341*	0.6***	0.653***	0.735***	0.717***	0.859***	0.969***	0.51***	0.513***	0.9***	1

Correlation: Studies on correlation (**Table 5**) were conducted to ascertain association between various traits at the phenotypic and genotypic levels (**Fig. 1**). Genetic correlation coefficients were larger than phenotype correlation coefficients in terms of magnitude. This illustrates a robust underlying correlation among multiple traits. The quantitative attribute of yield is controlled by a limited number of genes. Correlation studies assist in understanding the relationship between yield and the contributing traits. By strategically selecting from independent variables that influence yield, we can enhance its outcome. Correlation between traits is furnished in **Table 5**. Among the yield parameters that were looked at, traits like root fresh weight was significantly corelated with root dry weight (0.997) followed by whole plant fresh weight which exhibited strong significance and a favourable correlation with stem fresh weight (0.991) and stem dry weight (0.899). This suggested a positive correlation for plant yield with the other contributing traits and improvement of any of the traits might simultaneously enhance yield. Hence, indirect selection of the above traits aids in determining the high-yielding mutants in the population. Whole plant dry weight was also positively corelated with stem dry weight (0.969).

Path analysis: Path coefficient analysis developed by Dewey and Lu (1959) is a standardized partial regression coefficient that divides the correlation coefficient into measures of direct and indirect effects. It was performed to identify the direct and indirect contribution of different independent characters on dependent character yield. The association among the elements of yield and yield contributing traits may not be accurately depicted by the relationship of features as defined by the basic correlation coefficient. In contrast, path coefficient analysis enables a careful evaluation of certain direct and indirect character influences and quantifies the relative weight of each in determining ultimate yield. It revealed that stem fresh weight had highest direct effect (0.926) followed by stem dry weight (0.468), leaf dry weight (0.155) and leaf fresh weight (0.145) recorded positive and high direct effect on whole plant fresh weight per plant (Table 6). Therefore, selection based on the above mentioned characters would help in increasing the whole plant fresh weight. Path analysis suggested that all the characters having positive association with plant yield might also be directly contributing to stem yield and hence selection of genotypes may reliably done based on these characters. Similar results were reported by Srivastava *et al.* (2018) in Indian Ginseng, Dubey (2010) in ashwagandha, Sandesh *et al.* (2018) in *Oroxylum indicum* (L.) and Mastiholi *et al.* (2018) in *Salacia chinensis*.

To conclude, higher values of PCV, GCV, heritability, and GAM indicate a higher influence of environmental factors, as indicated by variability studies. Correlation analyses demonstrate the strong connections between leaf fresh weight, leaf dry weight, stem fresh weight, stem dry weight, root fresh weight, root dry weight, whole

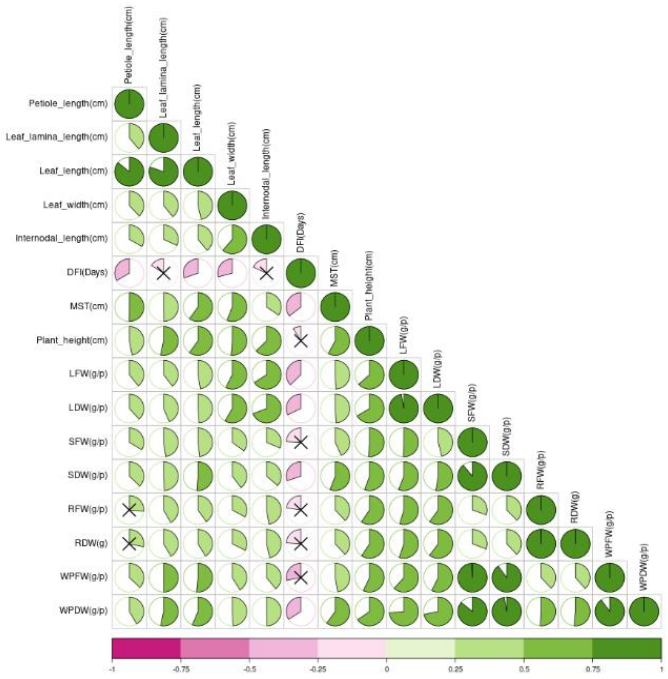

Fig. 1. Correlation chart between several genotypes of *Tinospora* characteristics

Table 6. Path analysis direct and indirect impact of yield component characteristics on yield in several genotypes of *Tinospora cordifolia*

	PTL	LLL	LL	LW	IL	DFI	MST	PH	LFW	LDW	SFW	SDW	RFW	RDW	WPDW	gen_ corr with main variable
PTL	-0.002	0	0	-0.003	0.001	0	0.002	0	0.037	0.043	0.019	0.091	0.001	0.018	-0.144	0.065
LLL	-0.001	0.001	0	-0.003	0.001	0	0.002	0	0.044	0.053	0.083	0.12	0.002	0.023	-0.186	0.138
LL	-0.001	0.001	0	-0.002	0.001	0	0.002	0	0.051	0.062	0.168	0.161	0.002	0.023	-0.237	0.23
LW	-0.001	0.001	0	-0.003	0.001	0	0.002	0	0.054	0.061	0.021	0.097	0.001	0.02	-0.171	0.084
IL	-0.001	0	0	-0.003	0.002	0	0.002	0	0.077	0.092	0.08	0.121	0.002	0.026	-0.228	0.17
DFI	0.001	0	0	0.001	-0.001	0.001	-0.001	0	-0.049	-0.052	-0.153	-0.114	-0.001	-0.011	0.174	-0.206
MST	-0.001	0.001	0	-0.003	0.001	0	0.002	0	0.041	0.048	0.029	0.106	0.001	0.019	-0.166	0.078
PH	-0.001	0	0	-0.001	0.001	0	0.001	-0.001	0.083	0.104	0.403	0.25	0.002	0.031	-0.373	0.5
LFW	0	0	0	-0.001	0.001	0	0.001	0	0.145	0.148	0.37	0.236	0.002	0.025	-0.4	0.526
LDW	0	0	0	-0.001	0.001	0	0.001	0	0.139	0.155	0.37	0.241	0.002	0.031	-0.415	0.523
SFW	0	0	0	0	0	0	0	0	0.058	0.062	0.926	0.408	0.001	0.012	-0.478	0.989
SDW	0	0	0	-0.001	0	0	0.001	0	0.073	0.08	0.807	0.468	0.001	0.018	-0.559	0.889
RFW	-0.001	0	0	-0.001	0.001	0	0.001	0	0.072	0.093	0.226	0.167	0.004	0.051	-0.288	0.325
RDW	-0.001	0	0	-0.001	0.001	0	0.001	0	0.073	0.094	0.226	0.168	0.004	0.051	-0.29	0.325
WPDW	0	0	0	-0.001	0.001	0	0.001	0	0.101	0.111	0.765	0.452	0.002	0.026	-0.579	0.877

(PTL- Petiole length (cm), LLL-Leaf lamina length (cm), LL-Leaf Length, LW-Leaf width (cm), IL-Internodal length (cm), DFI-Days to Flower Initiation (Days), MST- Main Stem Thickness (cm), PH- Plant height (cm), LFW- Leaf fresh weight (g/p), LDW- Leaf dry weight (g/p), SFW- Stem fresh weight (g/p), SDW- Stem dry weight (g/p), RFW- Root fresh weight (g/p), RDW- Root dry weight (g/p), WPFW- Whole plant fresh weight (g/p), WPDW- whole plant dry weight (g/p))

plant fresh weight, and whole plant dry weight with single plant yield in Tenospora. Path analysis reveals that stem fresh weight has maximum role in increasing overall yield. Therefore, selecting plants based on fresh leaf and stem weight would contribute to enhancing the weight of the entire plant. Incorporating these characteristics into selection criteria would be advantageous for increasing yield.

REFERENCES

Abhijeet, R. and Mokat, D. 2018. On vegetative propagation through stem cuttings in medicinally lucrative Tinospora species. *Journal of Pharmacognosy and Phytochemistry*, **7**(2): 2313-2318.

Akhilraj, B. C., Suresh, J., Rajamani, K., Kumar, M. and Gnanam, R. 2023. Influence of hormonal treatments on STEM cuttings through multiplication in therapeutically worthwhile Plant *Tinospora cordifolia*. *International Journal of Environment and Climate Change*, **13**(7): 680-686. [Cross Ref]

Devi, B., Singh, A. and Upadhyay, R.G. 2015. Morphological variability in Giloya [*Tinospora cordifolia* (willd) Miers] under changing scenario of climate in North Western Himalaya. *Environment Conservation Journal*, **16**(1&2): 133-137. [Cross Ref]

Dewey, D.R. and Lu, H.K. 1959. A correlation and path coefficients analysis of components of crested wheatgrass seed production. *Agronomy journal*, **51**(9): 515-518. [Cross Ref]

Dubey, R.B. 2010. Genetic variability, correlation and path analysis in ashwagandha (*Withania somnifera*). *Journal of Medicinal and Aromatic Plant Sciences*, **32**(3): 202-205.

Gopinath, P.P, Parsad, R., Joseph, B. and Adarsh, V. S. 2020. GRAPES: General Rshiny Based Analysis Platform Empowered by Statistics. https://www.kaugrapes.com/home. Version 1.0.0. DOI: 10.5281/zenodo.4923220.

Gufran, U., Shah, S.N., Chawhaan, P.H., Yogeshwar, M. and Mandal, A.K. 2015. Estimation of genetic parameters and association of growth characters in *Tinospora cordifolia* (Willd.) Miers ex Hook. F. & Thoms. *Indian Forester*, **141**(9): 941-945.

Chaudhari, S. and Shaikh, N. 2013. Gaduchi-the best ayurvedic herb. *The Pharma Innovation Journal,* **2**(4):97-102.

Chauhan, N.S. 1999. Medicinal and aromatic plants of Himachal Pradesh. Indus publishing, New Delhi.

Johnson, H.W., Robinson, H.F. and Comstock, R.E. 1955a. Estimates of genetic and environmental variability in soybeans. *Agronomy journal*, **47**(7): 314-318. [Cross Ref]

Johnson, H.W., Robinson, H.F. and Comstock, R.E. 1955b. Genotypic and phenotypic correlations in soybeans and their implications in selection. *Agronomy journal*, **47**(10): 477-483. [Cross Ref]

Joy, A., Harisha, C.R. and Acharya, R.N. 2012. Micrometric evaluation of two botanical source plants of Guduchi ie *Tinospora cordifolia* (Wild.) Miers and *Tinospora malabarica* (Lam.) Hook. F. & Thomson stem and leaf. *International Journal of Ayurvedic Medicine*, **12**(2): 219-225. [Cross Ref]

Kim, K.S., Seong, N.S., Chang, Y.H., Lee, S.T., Lee, J.I., Oak, H.C. and Chae, Y.A. 1995. Variation of plant characters and correlation analysis of its in *Bupleurum falcatum* L. *Korean Journal of Medicinal Crop Science*, **3**(1): 71-76.

Lush, J. L. 1940. Intra-sire correlations or regressions of offspring on dam as a method of estimating heritability of characteristics. *Journal of Animal Science*, 1: 293–30.

Mastiholi, L., Shetty, G.R. and Rajasekharan, P.E. 2018. Character association for fruit yield and yield traits in *Salacia chinensis* L.: A threatened medicinal plant. *Electronic Journal of Plant Breeding*, **9**(3): 873-878. [Cross Ref]

Rana, V., Thakur, K., Sood, R., Sharma, V. and Sharma, T.R. 2012. Genetic diversity analysis of *Tinospora cordifolia* germplasm collected from northwestern Himalayan region of India. *Journal of genetics*, **91**(1): 99. [Cross Ref]

Sandesh, M.S., Shetty, G.R. and Rajasekharan, P.E. 2018. Character association for yield traits in *Oroxylum indicum* (L.) Vent: A vulnerable medicinal tree. *Electronic Journal of Plant Breeding*, **9**(1): 226-232. [Cross Ref]

Sathish Kumar, R. Vanniarajan, C., Vetriventhan, M., Chandirakala, R., Saravanan, S. and Renuka R. 2022. Association and genetic variability studies for yield contributing traits in barnyard millet (*Echinochloa frumentacea* (Roxb.) Link). Mutants. *Biological Forum – An International Journal,* **14**(3): 474-479.

Sharma, A., Gupta, A., Singh, S. and Batra, A. 2010. *Tinospora cordifolia* (Willd.) Hook. F. & Thomson-A plant with immense economic potential. *Journal of Chemical and Pharmaceutical Research*, **2**(5): 327-333.

Sivasubramanian, S. and Madhava Menon, P. 1973. Genotypic and phenotypic variability in rice. *Madras Agricultural. J.ournal*, **60**(9-12): 1093-1096.

Spandana, U., Ali, S.L., Nirmala, T., Santhi, M. and Babu, S.S. 2013. A review on Tinospora cordifolia. *International Journal of Current Pharmaceutical Review and Research*, **4**(2): 61-68.

Srivastava, A., Gupta, A.K., Shanker, K., Gupta, M.M., Mishra, R. and Lal, R.K. 2018. Genetic variability, associations and path analysis of chemical and morphological traits in Indian ginseng [*Withania somnifera* (L.) Dunal] for selection of higher yielding genotypes. *Journal of ginseng research*, **42**(2): 158-164. [Cross Ref]

Stanely, P., Prince, M. and Menon, V.P. 2000. Hypoglycaemic and other related actions of *Tinospora cordifolia* roots in alloxan-induced diabetic rats. *Journal of ethno pharmacology,* **70**(1): 9-15. [Cross Ref]

Thakur, R.K., Rajpal, V.R., Rao, S.R., Singh, A., Joshi, L., Kaushal, P. and Raina, S.N. 2020. Induction and evaluation of colchitetraploids of two species of *Tinospora* Miers, 1851. *Comparative Cytogenetics*, **14**(2): 211-229. [Cross Ref]