Correlation and path coefficient analysis in spinach genotypes for yield and agronomic traits under Jalandhar, Punjab conditions

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ABSTRACT

The present study investigated the genotypic and phenotypic correlations and path coefficients among various morphological, physiological and yield-related traits in twenty spinach genotypes under the agro-climatic conditions of Jalandhar, Punjab. The experiment was conducted in a randomized block design with three replications. Correlation analysis revealed significant positive associations of first cutting yield with leaf area, number of leaves per plant, leaf length and leaf width at both genotypic and phenotypic levels. Path coefficient analysis further partitioned these correlations into direct and indirect effects. At the genotypic level, leaf area, leaf width and leaf length exhibited positive direct effects on first cutting yield, while the direct effect of the number of leaves per plant was negative despite its positive correlation. Similar trends were observed at the phenotypic level, with leaf area, leaf width and phenolics showing positive direct effects. The study highlights the importance of leaf area, leaf width and leaf length as key traits for direct selection to improve spinach yield in this region. Conversely, direct selection based solely on the number of leaves per plant, despite its positive correlation with yield, should be approached cautiously due to its negative direct effect. The findings provide valuable insights for spinach breeding programmes aimed at enhancing productivity and selecting for early emergence through traits like leaf length and leaf width, which showed negative correlation with days to emergence.

Keywords: Spinach; correlation; path coefficient; yield; traits; genotypes

INTRODUCTION

In India, total vegetables were cultivated over an area of 10,859 thousand hectares with an annual production of 200,445 thousand MT (Anon 2023). Spinach (*Spinacia oleracea* L), also known as Palak, is one of the most nutritious vegetables consumed throughout the world as salad or as cooked vegetable. It is a leafy cool season vegetable belonging to the family Chenopodiaceae. Spinach is a dioecious plant (Gyawali et al 2021) with higher pigment and carbohydrate content in females as compared to males. Cross pollination in spinach is generally assisted by wind. Being a highly cross-pollinated crop, huge amount of variability is observed in its population. It is native to central and western Asia (Jain et al 2022). China is the largest producer of spinach followed by USA.

In India, spinach is mostly cultivated in tropical and sub-tropical regions like Uttar Pradesh, West Bengal, Maharashtra, Rajasthan, Punjab, Haryana and Gujrat (Nasrabadi et al 2022). It has significant amount of beta carotene (Alhasnawi et al 2024), folate, vitamin C and calcium along with considerable amount of phosphorus, sodium and potassium. Spinach is a rich source of antioxidants and is among the vegetables with highest ORAC (oxygen radical absorbance capacity) (Gupta and Wagle 1998).

Genetic diversity is the cornerstone of crop improvement, as it provides the variability needed to select superior genotypes and develop improved varieties with enhanced yield, quality and stress tolerance (Swarup et al 2021). The success of any breeding programme largely depends on the availability and characterization of diverse germplasm (Asadi and

Hasandokht 2007, Anandhinatchiar et al 2024). Enhancing the yield and quality traits of spinach through breeding requires a deep understanding of the relationships among various agronomic and physiological characters. In this context, correlation and path coefficient analyses serve as essential statistical tools for plant breeders (Gerrano et al 2015, Reddy et al 2014). Correlation analysis provides insights into the degree and direction of association between pairs of traits, which is crucial in identifying traits that are directly or indirectly linked with yield (Sabaghnia et al 2014). However, correlation alone does not reveal the causal relationship among traits. To overcome this limitation, path coefficient analysis is employed. This method partitions the correlation coefficients into direct and indirect effects, thereby, offering a more precise understanding of how individual traits contribute to the overall yield. In spinach, applying these analyses helps in identifying key selection criteria for yield improvement by quantifying the contribution of various traits such as leaf area, plant height, number of leaves and biomass. The combined use of these statistical techniques facilitates more efficient selection strategies in breeding programmes aimed at enhancing productivity and quality in spinach.

Correlation coefficient helps us to find out the degree and direction of relationship between two or more traits and determines the component characters for effective selection to bring genetic improvement. It helps in indirect selection of important traits having low heritability through correlated traits with high heritability and low environmental influence.

Correlation coefficients are helpful in determining the components of a complex trait, however, an exact picture of the relative importance of direct and indirect influence of each component trait cannot be estimated. Path coefficient (Wright 1921, Dewey and Lu 1959) plays an important role, hereby, partitioning the correlations into direct and indirect effects and in determining their degree of relationship. When a dependent character governed by many independent characters is to be improved, then, sometimes, even character showing significant correlation with it may not be considered, as its correlation with the trait may be influenced by the indirect effects rather than directly. Under such circumstances, it is always more appropriate to split the correlation value into direct and indirect effects through path coefficient analysis.

MATERIAL and METHODS

The current study was conducted at the experimental farm of the Department of Agricultural Science, DAV University, Jalandhar, Punjab, starting in October 2019.

The experiment was structured as a randomized block design with three replications, utilizing a plot size of 5.4 m x 3 m and a row to row spacing of 20 cm. Twenty diverse spinach genotypes were planted in three rows within each plot, following recommended agricultural practices. The genotypes included: Green Star, Palak Harit Shobha, Super All Green, Evergreen, Supriya, All Green, Palak Harita, Komal Spinach, Palak All Green, Spinach Solan Harit, Green Flavour, Ananya Green, Samag Star, Spinach Green Hara Sona, Palak Beej, Pusa Harit (a check variety recommended for the region), All Green Composite, Local Selection 1, Local Selection 2 and Local Selection 3.

Planting occurred during the winter season of 2019-2020. Observations were meticulously recorded from five randomly selected competitive plants within each replication and their mean values were computed. Days to emergence were counted from sowing until seedling emergence. Leaf length and width were measured using a scale. Petiole length was measured from the base of the plant to the petiole tip with a scale and petiole diameter was determined using a digital Vernier caliper. The number of leaves on selected fresh plants was counted after cutting. Leaf area was calculated using the grid method. Days to first cutting were recorded from sowing until the first harvest and cutting yield was determined by weighing the fresh plants.

For bolting initiation, days were counted from sowing until 10 per cent of the plants developed stems 5 cm high. Regarding biochemical analyses, the quantities of chlorophyll 'a' and 'b' were calculated following the chlorophyll extraction protocol outlined by Hiscox and Israelstam (1979) and adopted by Richardson et al (2002), enabling the calculation of total chlorophyll content. Phosphorus was estimated according to the method described by Kitson and Mellon (1944). Phenol content was estimated using the method detailed by Sadasivam and Manickam (1997).

Genotypic and phenotypic correlation coefficients were studied among the genotypes.

Table 1. Estimates of correlation coefficient at genotypic level among different quantitative traits of spinach genotypes

Character	Leaf length	Leaf width	Petiole length	Petiole diameter	Leaves /plant	Leaf area	Days to first cutting	Bolting	Chlorophyll 'a'	Chlorophyll 'b'	Total chlorophyll	Phenolics	Phosphorus	First cutting yield
Days to emergence	–1.05*	–0.88*	–0.43	–0.49*	–0.51*	–0.45*	0.06	0.27	0.59*	0.42	0.52*	–0.52*	–0.29	–0.50*
Leaf length		0.68	0.97*	0.38	0.55*	0.51*	0.35	–0.38	–0.58*	–0.09	–0.36	0.50*	–0.01	0.71*
Leaf width			0.82*	0.45*	0.60*	0.57*	0.21	0.03	–0.58*	–0.35	–0.48*	0.44	0.05	0.56*
Petiole length				0.46*	0.13	0.08	0.24	0.09	–0.39	–0.20	–0.30	0.04	0.37	0.03
Petiole diameter					0.33	0.31	0.13	0.01	0.06	0.17	0.11	0.10	0.13	0.27
Leaves/plant						0.99*	0.01	–0.39	–0.22	–0.36	–0.28	0.30	–0.02	0.90*
Leaf area							0.05	–0.39	–0.19	–0.35	–0.26	0.29	–0.04	0.92*
Days to first cutting								0.17	0.04	–0.03	0.01	–0.41	0.09	0.19
Bolting									0.01	0.01	0.01	–0.18	0.05	–0.30
Chlorophyll 'a'										0.96*	0.99*	–0.54*	–0.56*	–0.12
Chlorophyll 'b'											0.99*	–0.52	–0.43	–0.22
Total chlorophyll												–0.54	–0.50	–0.17
Phenolics													–0.05	0.29
Phosphorus														–0.19

*Significant at 5% LoS

RESULTS and DISCUSSION

Genotypic correlation coefficient: The data given in Table 1 show that days to emergence had significant positive correlation with chlorophyll 'a' (0.59) and total chlorophyll (0.52), whereas, significant negative correlation of the trait was observed with leaf length (–1.05), leaf width (–0.88), petiole diameter (–0.49), number of leaves per plant (–0.51), leaf area (–0.45), phenolics (–0.52) and first cutting yield (–0.50). Leaf length showed significant positive correlation with petiole length (0.97), number of leaves per plant (0.55), leaf area (0.51), phenolics (0.50) and first cutting yield (0.71), whereas, significant negative correlation of leaf length with leaf length (–1.05) and chlorophyll 'a' (–0.58) was observed. Leaf width showed significant positive correlation with petiole length (0.82), petiole diameter (0.45), number of leaves per plant (0.60), leaf area (0.57) and first cutting yield (0.56), whereas, with days to emergence (–0.58), total chlorophyll (–0.48) and chlorophyll 'a' (–0.58) had significant negative correlation with it. Petiole length showed significant positive correlation with petiole diameter (0.46) and leaf width (0.82) and significant negative correlation with none of the traits. Petiole diameter showed significant positive correlation with petiole length (0.46) and leaf width (0.45) and significant negative correlation with days to emergence (–0.49). Number of leaves per plant showed positive correlation with leaf area (0.99), first cutting yield (0.90), leaf length (0.55) and leaf width (0.60) and negative with days to emergence (–0.51). Leaf area showed significant positive correlation with first cutting yield (0.92), number of leaves per plant (0.99) and leaf length (0.51) and significant negative correlation with days to emergence (–0.45). Days to first cutting and bolting showed no significant positive or negative correlation with any of the traits. Chlorophyll 'a' was significantly positively correlated with total chlorophyll (0.99), chlorophyll 'b' (0.96) and days to emergence (0.59), however, showed significant negative correlation with leaf length (–0.58), leaf width (–0.58), phenolics (–0.54) and phosphorus (–0.56). Chlorophyll 'b' exhibited significant positive correlation with total chlorophyll (0.99) and chlorophyll 'a' (0.96). Total chlorophyll as discussed showed positive correlation with days to emergence, chlorophyll 'a' and chlorophyll 'b'. Phenolics showed significant positive correlation with leaf length (0.50) and significant negative with chlorophyll 'a' (–0.54) and days to emergence (–0.52). Phosphorus showed significant positive correlation with none of the traits but exhibited significant negative correlation with

Table 2. Estimates of correlation coefficient at phenotypic level among different quantitative traits of spinach genotypes

Character	Leaf length	Leaf width	Petiole length	Petiole diameter	Leaves /plant	Leaf area	Days to first cutting	Bolting	Chlorophyll 'a'	Chlorophyll 'b'	Total chlorophyll	Phenolics	Phosphorus	First cutting yield
Days to emergence	–0.33*	–0.40*	–0.34*	0.38*	–0.36*	–0.32*	0.13	0.10	0.33*	0.29*	0.35*	–0.41*	–0.22	–0.37
Leaf length		0.54*	0.18	0.27*	0.20	0.19	0.07	–0.22	–0.12	–0.13	–0.14	0.25	0.03	0.33
Leaf width			0.39*	0.35*	0.31*	0.28*	0.07	0.05	–0.22	–0.23	–0.25*	0.24	0.06	0.37*
Petiole length				0.39*	0.13	0.08	0.13	0.07	–0.28*	–0.17	–0.26*	0.03	0.34*	0.01
Petiole diameter					0.29*	0.27*	0.12	0.02	0.08	0.14	0.12	0.12	0.13	0.27*
Leaves/plant						0.98*	0.04	–0.35*	–0.20	–0.32*	–0.28*	0.24	–0.02	0.82*
Leaf area							0.06	–0.33*	–0.17	–0.31*	–0.26*	0.24	–0.03	0.84*
Days to first cutting								0.14	–0.01	–0.03	–0.02	–0.30*	0.05	0.15
Bolting									0.04	–0.00005	0.02	–0.17	0.05	–0.25
Chlorophyll 'a'										0.57*	0.91*	–0.44*	–0.46*	–0.13
Chlorophyll 'b'											0.86*	–0.41*	–0.37*	–0.21
Total chlorophyll												–0.48	–0.47*	–0.19
Phenolics													–0.03	0.29*
Phosphorus														0.17

*Significant at 5% LoS

chlorophyll 'a' (–0.56). Significant positive correlation of first cutting yield was observed with number of leaves per plant, leaf length, leaf width and leaf area and significant negative with days to emergence.

Phenotypic correlation coefficient: The data in Table 2 exhibit that days to emergence had significant positive correlation with petiole diameter (0.38), total chlorophyll (0.35), chlorophyll 'a' (0.33), chlorophyll 'b' (0.29) and significant negative correlation with phosphorus (–0.22), leaf area (–0.32), leaf length (–0.33), petiole length (–0.34), number of leaves per plant (–0.36), leaf width (–0.40) and phenolics (–0.41). Leaf length showed significant positive correlation with leaf width (0.54) and petiole diameter (0.27), while, leaf width had significant positive correlation with petiole length (0.39), petiole diameter (0.35), number of leaves per plant (0.31), leaf area (0.28) and days to first cutting (0.37). Both these traits showed significant negative correlation with days to emergence as discussed above. Leaf width also exhibited significant negative correlation with total chlorophyll (–0.25). Petiole length showed significant positive correlation with leaf width (0.39), petiole diameter (0.39) and phosphorus (0.34), whereas, its significant negative correlation was observed with days to emergence (–0.34), total chlorophyll (–0.26) and chlorophyll 'a' (–0.28). Petiole diameter showed significant positive correlation with days to emergence, leaf length, leaf width and petiole length along with other traits like leaf per plant (0.29) and leaf area (0.27). It had significant negative correlation with none of the traits. Number of leaves per plant exhibited significant positive correlation with leaf area (0.98) and first cutting yield (0.82) along with previously discussed other traits like leaf width and petiole diameter. Similarly, its significant negative correlation with total chlorophyll (–0.28), chlorophyll 'b' (–0.32) and bolting (–0.35) was also observed along with days to emergence. Leaf area exhibited positive correlation with previously discussed traits like leaf width, petiole diameter and number of leaves per plant along with first cutting yield (0.84) and showed significant negative correlation with total chlorophyll (–0.26), chlorophyll 'b' (–0.31) and bolting (–0.33) along with days to emergence. Significant negative correlation of days to first cutting was observed with phenolics (–0.30) and of bolting with leaves per plant and leaf area. However, no significant positive correlation with any other trait was observed in both these characters. Chlorophyll 'a' showed significant positive correlation with chlorophyll 'b' (0.57) and total chlorophyll (0.91) along with days to emergence and significant negative correlation with phenolics (–0.44) and phosphorus (0.46) along with petiole length. Chlorophyll 'b' showed significant positive correlation with total chlorophyll (0.86) along with days to emergence and chlorophyll 'a', whereas, significant negative correlation with previously discussed traits like number of leaves per plant and leaf area along with phenolics (0.41) and phosphorus (0.37). Total chlorophyll showed significant negative correlation with leaf width, petiole length, number of leaves per plant and leaf area along with phosphorus (0.47) and significant positive correlation with days to emergence, chlorophyll 'a' and chlorophyll 'b'.

Thus it was observed that phenolics were only significantly positively correlated with first cutting yield, however, negatively correlated with days to emergence, days to first cutting, chlorophyll 'a' and chlorophyll 'b'. Similarly, phosphorus was only positively correlated with petiole length, however, negatively with chlorophyll 'a', chlorophyll 'b' and total chlorophyll. First cutting yield showed highest significant positive correlation with leaf area followed by number of leaves per plant, leaf width, phenolics and petiole diameter.

Path coefficient analysis

The estimates of direct and indirect effects are given in Tables 3 and 4 as phenotypic as well as genotypic path coefficient.

Significant positive correlation of first cutting yield was observed with number of leaves per plant, leaf length, leaf width and leaf area. However, positive direct effects were only observed in leaf area (1.24935) and leaf width (0.29203) and leaf length (0.18405). Number of leaves per plant had direct negative effect (–0.31018) on first cutting yield and contributed to it through leaf length, leaf width, petiole diameter, leaf area, days to first cutting, chlorophyll 'a', chlorophyll 'b', phenolics and phosphorus as indicated by indirect positive effects. First cutting yield showed highest significant positive phenotypic correlation with leaf area, number of leaves per plant, leaf width, phenolics and petiole diameter. However, the direct effects were positive only for leaf area (1.12845), leaf width (0.06196) and phenolics (0.03847). Number of leaves per plant (–0.35955) contributed indirectly through days to emergence, leaf length, leaf width, leaf area, days to first cutting, chlorophyll 'a', chlorophyll 'b', phenolics and phosphorus and petiole diameter (–0.00619) through

Table 3. Estimates of direct and indirect genotypic effects of different quantitative traits of Spinach genotypes

Character	Days to emergence	Leaf length	Leaf width	Petiole length	Petiole diameter	Leaves /plant	Leaf area	Days to first cutting	Bolting	Ch 'a'	Ch 'b'	Total ch	Phenolics	P
Days to emergence	**0.27047**	–0.19330	–0.25822	0.18447	–0.00495	0.15836	–0.56252	0.01014	0.01880	–2.22406	–0.78889	2.89258	–0.01403	0.00699
Leaf length	–0.28407	**0.18405**	0.19856	–0.24567	0.00384	–0.17049	0.63395	0.05432	–0.02644	2.17725	0.16229	–1.98211	0.01367	0.00031
Leaf width	–0.23915	0.12514	**0.29203**	–0.35151	0.00454	–0.18697	0.70968	0.03173	0.00194	2.16281	0.65931	–2.66082	0.01198	–0.00121
Petiole length	–0.11675	0.10580	0.24021	**–0.42735**	0.00458	–0.03958	0.09548	0.03764	0.00663	1.45481	0.37640	–1.69761	0.00103	–0.00893
Petiole diameter	–0.13339	0.07039	0.13195	–0.19518	**0.01004**	–0.10262	0.39183	0.01969	0.00099	–0.23703	–0.31306	0.62725	0.00284	–0.00318
Leaves/plant	–0.13808	0.10116	0.17603	–0.05453	0.00332	**–0.31018**	1.24347	0.00179	–0.02736	0.81046	0.66223	–1.57066	0.00817	0.00062
Leaf area	–0.12178	0.09339	0.16589	–0.03266	0.00315	–0.30872	**1.24935**	0.00716	–0.02709	0.69792	0.65315	–1.46729	0.00796	0.00098
Days to first cutting	0.01784	0.06503	0.06026	–0.10463	0.00129	–0.00362	0.05816	**0.15374**	0.01224	–0.16790	0.06337	0.04734	–0.01119	–0.00221
Bolting	0.07280	–0.06965	0.00813	–0.04059	0.000124	0.12146	–0.48452	0.02694	**0.06986**	–0.02859	–0.01684	0.04612	–0.00500	–0.00124
Chlorophyll 'a'	0.16115	–0.10735	–0.16921	0.16656	0.00064	0.06735	–0.23359	0.00692	0.00054	**–3.73278**	–1.80302	5.52025	–0.01475	0.01334
Chlorophyll 'b'	0.11401	–0.01596	–0.10287	0.08594	0.00168	0.10975	–0.43600	–0.00521	0.00063	–3.59601	**–1.87159**	5.50311	–0.01437	0.01037
Total chlorophyll	0.14063	–0.06557	–0.13968	0.13041	0.00113	0.08757	–0.32952	0.00131	0.00058	–3.70396	–1.85138	**5.56320**	–0.01471	0.01207
Phenolics	–0.13998	0.9282	0.12899	–0.01628	0.00105	–0.09343	0.36661	–0.06348	–0.01290	2.03022	0.99179	–3.–1909	**0.02711**	0.00111
Phosphorus	–0.07912	–0.00239	0.01477	–0.15980	0.00134	0.00806	–0.05140	0.01419	0.00363	2.08379	0.81233	–2.81086	–0.00126	**–0.02389**

Residual effect: 0.2974, Bold (diagonal) values indicate direct effects, Ch: Chlorophyll, P: Phosphorus

Table 4. Estimates of direct and indirect phenotypic effects of different quantitative traits of Spinach genotypes

Character	Days to emergence	Leaf length	Leaf width	Petiole length	Petiole diameter	Leaves /plant	Leaf area	Days to first cutting	Bolting	Ch 'a'	Ch 'b'	Total ch	Phenolics	P
Days to emergence	**–0.15406**	–0.04305	–0.02486	0.03665	0.00234	0.12818	–0.36776	0.01824	0.00479	–0.41287	–0.25488	0.66999	–0.01581	0.04120
Leaf length	0.05045	**0.13150**	0.03375	–0.02007	–0.00171	–0.07364	0.21723	0.00972	–0.01105	0.1578	0.11345	–0.27378	0.00970	–0.00924
Leaf width	0.06181	0.07159	**0.06196**	–0.04165	–0.00218	–0.11279	0.32420	0.01030	0.00260	0.27771	0.19884	–0.48067	0.00930	–0.00910
Petiole length	0.05289	0.02472	0.02418	**–0.10672**	–0.00241	–0.04771	0.09660	0.01798	0.00353	0.36190	0.14978	–0.50674	0.00137	–0.06094
Petiole diameter	0.05834	0.03638	0.02180	–0.04151	**–0.00619**	–0.10459	0.30536	0.01718	0.00106	–0.10306	–0.11836	0.22598	0.00502	–0.1911
Leaves/plant	0.05491	0.02691	0.01943	–0.01416	–0.00180	**–0.35955**	1.10916	0.00635	–0.01731	0.25122	0.27942	–0.54246	0.00923	0.00506
Leaf area	0.05019	0.02529	0.01780	–0.00914	–0.00167	–0.35340	**1.12845**	0.00832	–0.01632	0.22099	0.27373	–0.50769	0.00941	0.00643
Days to first cutting	–0.02044	0.00929	0.00464	–0.01396	–0.00077	–0.01661	0.06827	**0.13747**	0.00686	0.01399	0.02901	–0.04516	–0.01159	–0.00861
Bolting	–0.01506	–0.02964	0.00328	–0.00768	–0.00013	0.12710	–0.03761	0.01927	**0.04897**	–0.04510	0.00043	0.04289	–0.00653	–0.00928
Chlorophyll 'a'	–0.05090	–0.01660	–0.01377	0.03092	–0.00051	0.07231	–0.19962	–0.00154	0.00177	**–1.24949**	–0.49315	1.72505	–0.01713	0.07917
Chlorophyll 'b'	–0.04560	–0.01732	–0.01431	0.01857	–0.00085	0.11671	–0.35885	–0.00463	–0.00002	–0.71569	**–0.86054**	1.62019	–0.01572	0.06517
Total chlorophyll	–0.5461	–0.01904	–0.01576	0.02862	–0.00074	0.10323	–0.30321	–0.00329	0.00111	–1.14055	–0.73814	**1.88924**	–0.01860	0.08244
Phenolics	0.06327	0.03313	0.01496	–0.00379	–0.00081	–0.08622	0.27591	–0.04138	–0.00830	0.55579	0.35146	–0.91278	**0.03847**	0.01030
Phosphorus	0.03590	0.00687	0.00319	–0.03680	–0.00067	0.01028	–0.04108	0.00669	0.00257	0.55953	0.31738	–0.88123	–0.00224	**–0.15370**

Residual effect: 0.2007, Bold (diagonal) values indicate direct effects, Ch: Chlorophyll, P: Phosphorus

days to emergence, leaf length, leaf width, leaf area, days to first cutting, bolting, total chlorophyll and phenolics. The combined results of correlation and path analysis revealed that to improve yield of spinach direct selection for higher leaf width, leaf length and leaf area can be done, whereas, direct selection for number of leaves per plant showing positive correlation with first cutting yield but negative path coefficient should be avoided. Traits like leaf length and leaf width showed negative correlation with days to emergence, therefore, via selection of these traits, early emergence genotypes can also be selected.

Singh et al (2008) reported positive correlation of leaf length with yield per plant which is in line with the results of the present study. Varalakshmi and Devaraju (2010) also reported positive correlation of number of leaves per plant, leaf length and leaf width with high yield in Indian spinach. Eftekhari et al (2010) reported positive correlation of petiole length, petiole diameter and leaf width in Iranian spinach. Sarker et al (2014) also reported positive correlation of leaf length and leaf width with yield per plant and correlation of various morphological traits with the biochemical traits in amaranth. Bhargava et al (2004) found delayed bolting as a desirable trait in vegetable amaranth.

CONCLUSION

The study provides a comprehensive understanding of the interrelationships among various traits and their direct and indirect effects on the first cutting yield of spinach genotypes under the agro-climatic conditions of Jalandhar, Punjab. The consistent significant positive correlations observed between first cutting yield and leaf area, leaf length and leaf width at both genotypic and phenotypic levels underscore the importance of these morphological traits in determining yield potential. Path coefficient analysis further elucidated the causal relationships, revealing that direct selection for higher leaf area, leaf width and leaf length is likely to be effective in improving spinach yield in this region.

While the number of leaves per plant showed a strong positive correlation with yield, its negative direct effect suggests that indirect effects through other yield-contributing traits drive this association, warranting cautious consideration in direct selection.

Furthermore, the negative correlation of leaf length and leaf width with days to emergence indicates the potential for selecting early-emerging genotypes by focusing on these morphological traits. These findings offer valuable insights for breeders in formulating efficient selection strategies aimed at enhancing spinach productivity and quality, ultimately contributing to improved agricultural practices in similar agro-ecological zones.

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