Performance of spinach genotypes for yield and associated traits under north Indian plain conditions

DEEPAK SHARMA[1], SHIVANI SHARMA[2*] and JEENIA THALYARI[3]

[1]School of Agricultural Sciences, Baddi University of Emerging Sciences and Technology Baddi, District Solan 173205 Himachal Pradesh, India
[2]Faculty of Agriculture, Maharishi Markandeshwar University Mullana, Ambala 133202 Haryana, India
[3]Faculty of Agricultural Sciences, DAV University, Jalandhar 144012 Punjab, India
[*]Email for correspondence: shivanisharma050296@gmail.com

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ABSTRACT

Spinach (*Spinacia oleracea* L), a nutrient-rich leafy vegetable widely consumed across the globe, holds significant agronomic and nutritional importance. The present investigations were carried out at the experimental farm of DAV University, Jalandhar, Punjab, during the winter season of 2019-2020 to evaluate genetic variability, analyze variance and assess mean performance across twenty diverse spinach genotypes. The experiment followed a randomized block design with three replications. Significant genotypic differences were observed for all fifteen quantitative and biochemical traits, indicating a wide genetic base. Traits such as leaf area, number of leaves per plant and first cutting yield exhibited high variability, suggesting their potential for effective selection. Genotypes such as Ananya Green, Komal Spinach and Supriya consistently outperformed others in multiple traits including yield and vegetative growth, while All Green and Local Selections showed superior biochemical profiles with higher chlorophyll and phenolic content. The findings underscore the potential of these genotypes for future breeding programmes focused on yield enhancement, early maturity and improved nutritional quality in spinach cultivation under north Indian agro-ecological conditions.

Keywords: Spinach; analysis of variance; mean performance; north Indian plains

INTRODUCTION

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, with higher pigment and carbohydrate content in females as compared to males (Gyawali et al 2021). 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, Swarup et al 2021). Genetic improvement through selection of high-performing and stable genotypes is a crucial step toward enhancing productivity and sustainability in spinach cultivation (Asadi and Hasandokht 2007, Anandhinatchiar et al 2024). Understanding the extent of genetic variability and identifying superior genotypes are foundational to successful crop improvement programmes (Gerrano et al 2015, Reddy et al 2014). Analysis of variance (ANOVA) serves as a powerful statistical tool to detect significant differences among genotypes for various morphological and yield-related traits. Additionally, mean performance analysis helps in identifying

promising genotypes that exhibit desirable traits under specific environmental conditions (Sabaghnia et al 2014).

The present study was undertaken to evaluate the genetic variability, analyse variance and assess the mean performance of a diverse set of spinach genotypes under the agro-ecological conditions of the north Indian plains. The findings aim to provide valuable insights for breeders and researchers in selecting superior genotypes for further improvement and large scale cultivation.

MATERIAL and METHODS

The current study was conducted at the experimental farm of the Department of Agriculture, 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 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 (1992).

Analysis of variance for various quantitative traits and descriptive statistics of growth and biochemical traits of twenty spinach genotypes were studied.

RESULTS and DISCUSSIO

Analysis of variance

Perusal of data in Table 1 reveals that the mean sum of square due to genotypes was significant at the 5 per cent level for all the 15 quantitative traits studied, namely: days to emergence, leaf length, leaf width, petiole length, petiole diameter, number of leaves per plant, leaf area, days to first cutting, first cutting yield, bolting, chlorophyll 'a', chlorophyll 'b', total chlorophyll, phenolics and phosphorus. This indicates the presence of considerable genetic variability among the spinach genotypes under investigation. The replication mean sum of square was found to be non-significant for all traits, suggesting minimal environmental influence on trait expression across replications. The significant genotypic differences observed underscore the potential for selection and genetic improvement. Similar findings of substantial variability in spinach genotypes have been reported by Singh et al (2008), Eftekhari et al (2010), Sarker et al (2014), Reddy et al (2014), Sabaghnia et al (2014) and Wu et al (2000) and Kanthaswamy (2006) in related leafy vegetables such as amaranthus.

Mean performance of the genotypes

Twenty spinach genotypes were evaluated for their performance for growth traits and were compared with one check: Pusa Harit (one of the high yielding varieties recommended for Jalandhar, Punjab) and the results were interpreted against it. The mean values of each trait for all the genotypes are given in Table 2.

Days to emergence: There existed statistically significant differences among genotypes. The number of days taken for seedling emergence ranged from 4.00 (Supriya) to 8.00 days (Local Selection 3), with a mean of 5.30 days.

Table 1. Analysis of variance for various quantitative traits of spinach genotypes

Characters	Mean sum of square (replications) (df=2)	Mean sum of square (genotypes) (df = 38)	Error (df = 76)
Days to emergence	00.12	03.05*	00.50
Leaf length	00.17	00.92*	00.49
Leaf width	00.25	01.07*	00.45
Petiole length	00.17	06.92*	00.24
Petiole diameter	00.02	00.42*	00.01
Number of leaves/plant	00.22	23.94*	00.76
Leaf area	07.14	159.89*	03.31
Days to first cutting	08.02	14.09*	02.88
First cutting yield	00.69	98.28*	03.03
Bolting	33.45	124.75*	14.31
Chlorophyll 'a'	00.01	04.28*	00.59
Chlorophyll 'b'	00.09	02.99*	00.23
Total chlorophyll	00.12	12.94*	00.44
Phenolics	00.04	00.35*	00.02
Phosphorus	00.00	0.007*	0.0001

*Significant at $p \leq 0.05$

Table 2. Descriptive statistics of growth characteristics of spinach genotypes

Genotype	Days to emergence	Leaf length (cm)	Leaf width (cm)	Petiole length (cm)	Petiole diameter (mm)
Green Star	4.33	7.17	5.21	6.40	1.54
Palak Harit Shobha	4.44	7.92	5.07	7.27	2.38
Super All Green	6.00	7.33	4.90	8.33	2.20
Evergreen	5.00	7.48	5.26	6.19	2.71
Supriya	4.00	7.35	4.45	6.09	2.44
All Green	5.33	8.06	4.93	5.80	1.74
Komal Spinach	5.00	7.77	5.12	4.77	2.23
Palak All Green	5.67	7.46	4.24	4.64	1.37
Spinach Solan Harit	5.33	7.46	5.24	4.40	2.08
Green Flavour	4.67	8.80	5.10	4.07	1.68
Ananya Green	5.67	7.53	4.43	3.29	2.14
Samag Star	5.00	7.17	4.21	3.39	1.69
Spinach Green Hara Sona	5.33	7.06	4.05	3.89	1.60
Palak Beej	7.33	6.68	3.59	3.51	1.74
All Green Composite	5.67	7.39	3.85	4.49	2.02
Local Selection 1	4.67	7.05	4.82	3.81	2.13
Local Selection 2	4.67	7.71	3.98	3.55	2.38
Local Selection 3	8.00	6.40	3.87	3.24	1.55
Palak Harita	4.33	8.44	5.27	7.24	2.46
Pusa Harit (standard check)	6.33	7.17	3.61	4.59	1.86
Overall mean	5.3	7.47	4.56	4.94	1.99
Range	4.00-8.00	6.40-8.80	3.59-5.27	3.24-8.33	1.37-2.71
$CD_{0.05}$	1.17	1.12	0.82	0.82	0.19
CV	13.29	14.74	14.75	10.07	5.98

Table 2. Contd…..

Genotype	Number of leaves/plant	Leaf area (cm^2)	Days to first cutting	First cutting yield (g)	Bolting
Green Star	10.67	31.49	40.33	33.20	93.33
Palak Harit Shobha	8.33	26.17	45.67	29.53	93.33
Super All Green	7.00	22.63	45.33	29.46	93.33
Evergreen	10.00	29.98	43.33	30.80	89.00
Supriya	11.00	32.67	42.00	33.10	83.67
All Green	7.67	24.58	42.67	30.69	76.00
Komal Spinach	14.67	41.16	43.33	43.07	86.33
Palak All Green	7.33	23.61	43.00	31.16	87.33
Spinach Solan Harit	6.33	21.09	41.00	26.31	91.33
Green Flavour	9.00	28.09	44.33	36.41	90.00
Ananya Green	15.33	46.17	43.33	44.89	76.00
Samag Star	8.67	26.62	39.00	29.52	78.00
Spinach Green Hara Sona	6.67	21.52	46.00	27.26	79.33
Palak Beej	4.67	15.31	43.67	21.66	92.00
All Green Composite	6.00	19.94	38.67	23.22	83.33
Local Selection 1	6.67	22.22	40.67	32.71	93.33
Local Selection 2	6.67	22.80	44.33	33.83	92.33
Local Selection 3	5.33	21.25	44.33	27.17	94.33
Palak Harita	9.00	27.16	43.00	35.27	78.00
Pusa Harit (standard check)	6.67	21.57	39.67	27.39	88.67
Overall mean	8.38	26.30	42.61	31.33	86.95
Range	4.67-15.33	15.31-46.17	38.67-46.00	21.66-44.89	76.00-94.33
$CD_{0.05}$	1.44	3.00	2.80	2.87	6.25
CV	10.40	6.90	3.97	5.55	4.35

Leaf length: Leaf length varied from 6.40 cm (Local Selection 3) to 8.80 cm (Green Flavour), with an overall mean of 7.47 cm. There existed considerable genotypic variability. Several genotypes such as Green Flavour, Palak Harita, All Green, Palak Harit Shobha, Komal Spinach and Local Selection 2 exceeded the population mean, indicating their potential for breeding programmes targeting larger leaf traits.

Leaf width: Leaf width ranged from 3.59 (Palak Beej) to 5.27 cm (Palak Harita), averaging 4.56 cm across genotypes.

Petiole length: Petiole length showed the widest range, from 3.24 cm (Local Selection 3) to 8.33 cm (Super All Green). There was a stable expression of this trait across genotypes. Genotypes like Super All Green, Palak Harit Shobha and Palak Harita showed superior petiole length, making them favourable for increased biomass.

Petiole diameter: Petiole diameter ranged from 1.37 mm (Palak All Green) to 2.71 mm (Evergreen), with a mean of 1.99 mm. The trait displayed the lowest variability among the five, suggesting that it is relatively stable and less influenced by environmental factors. Notably, Evergreen, Palak Harita, Supriya, Palak Harit Shobha and Local Selection 2 exhibited higher petiole diameters.

Number of leaves per plant: The number of leaves per plant ranged from 4.67 in Palak Beej to 15.33 in Ananya Green, with an overall mean of 8.38. Genotypes such as Ananya Green and Komal Spinach recorded a significantly higher number of leaves, suggesting better vegetative development and greater leaf production potential. There existed significant and useful variation among the genotypes.

Leaf area: Leaf area varied substantially, ranging from 15.31 cm^2 in Palak Beej to 46.17 cm^2 in Ananya Green, with a population mean of 26.30 cm^2. The genotypes Ananya Green and Komal Spinach showed larger leaf areas, which may be associated with higher photosynthetic capacity and biomass accumulation. Significant genotypic variation was present among the genotypes.

Days to first cutting: Days to first cutting ranged from 38.67 in All Green Composite to 46.00 in Spinach Green Hara Sona, with a mean of 42.61 days. Genotypes such as All Green Composite, Samag Star, Pusa Harit, Green Star and Spinach Solan Harit were relatively early maturing and thus more suitable for quick harvesting. This trait exhibited the lowest variability reflecting the reliable genetic expression of this trait with minimal environmental influence.

First cutting yield: First cutting yield showed notable variation among genotypes, ranging from 21.66 g in Palak Beej to 44.89 g in Ananya Green, with a mean of 31.33 g. High-yielding genotypes such as Ananya Green and Komal Spinach demonstrated strong yield potential and could be utilized in breeding for productivity enhancement. There were statistically meaningful differences among genotypes.

Bolting: Bolting tendency, which influences the commercial lifespan of spinach, ranged from 76.00 in All Green and Ananya Green to 94.33 in Local Selection 3, with an average of 86.95. Genotypes such as All Green, Ananya Green, Samag Star, Palak Harita and Spinach Green Hara Sona exhibited delayed bolting, a desirable trait for prolonged vegetative growth. This trait showed stable trait expression with significant genotypic differences.

The evaluated spinach genotypes exhibited statistically significant variability for all the quantitative traits studied, indicating a broad genetic base within the material. Traits such as leaf area, number of leaves per plant and first cutting yield showed considerable variation, suggesting strong potential for selection and improvement. Genotypes like Ananya Green, Komal Spinach and Supriya consistently performed well across multiple traits, highlighting their promise for future breeding programmes aimed at enhancing vegetative growth, early maturity and yield. The stable expression observed in traits like petiole diameter and days to first cutting also suggests the possibility of achieving reliable trait inheritance under diverse environmental conditions. The presence of significant genetic diversity among the genotypes provides a valuable resource for genetic enhancement and varietal development in spinach.

Descriptive statistics of biochemical traits of spinach genotypes

The biochemical traits of twenty spinach genotypes, as summarized in Table 3, reveal significant variability in chlorophyll content, phenolics and phosphorus concentration, highlighting their potential for use in nutritional improvement and breeding strategies.

Chlorophyll 'a': Chlorophyll 'a' content varied considerably, ranging from 3.64 mg per g in Green Star to 7.69 mg per g in All Green, with an overall mean of 5.99 mg per g. Genotypes having higher chlorophyll 'a' values, suggested better photosynthetic potential and possibly enhanced vegetative vigour.

Chlorophyll 'b': Chlorophyll 'b'ranged from 1.28 mg per g in Palak Harit Shobha to 4.47 mg per g in All Green, with a mean of 3.33 mg per g . Higher values in genotypes indicate their strong adaptability and photosynthetic efficiency under varying light conditions.

Total chlorophyll: Total chlorophyll content, a key indicator of photosynthetic capacity, showed substantial variation among genotypes, from 5.00 (Palak Harit Shobha) to 12.11 (All Green) mg per g, with an average of 9.29 mg per g. Genotypes such as All Green, Local Selection 3, Local Selection 2 and Palak Beej exhibited superior chlorophyll content, making them valuable for selection in productivity-oriented breeding programmes.

Phenolic content: Phenolic content ranged from 1.37 mg per g in Spinach Green Hara Sona to 2.49 mg per g in Samag Star, averaging 1.91 mg per g across genotypes. Genotypes like Samag Star, Palak All Green, Spinach Solan Harit and Palak Harita recorded higher phenolic concentrations, which are important for antioxidant activity and contribute to health-promoting properties of spinach.

Phosphorus: Phosphorus content ranged between 0.02 mg per g in Palak All Green and Spinach Solan Harit to 0.23 mg per g in Palak Harit Shobha, with an overall mean of 0.07 mg per g. Though the variation was relatively small, genotypes such as Palak Harit Shobha and Samag Star demonstrated higher phosphorus levels, which are important for plant metabolism and nutritional quality.

Overall, the data indicate significant biochemical diversity among the spinach genotypes, with several showing desirable combinations of chlorophyll, phenolic and phosphorus content. This variability is crucial for enhancing both agronomic performance and nutritional value through targeted breeding efforts.

Table 3. Descriptive statistics of biochemical traits in twenty spinach genotypes

Genotypes	Chlorophyll 'a' (mg/g)	Chlorophyll 'b' (mg/g)	Total chlorophyll (mg/g)	Phenolics (mg/g)	Phosphorus (mg/g)
Green Star	3.64	1.43	5.06	1.93	0.09
Palak Harit Shobha	3.73	1.28	5.00	1.84	0.23
Super All Green	6.45	4.29	10.70	1.74	0.06
Evergreen	5.86	3.56	9.38	1.92	0.06
Supriya	6.77	3.33	10.07	2.18	0.08
All Green	7.69	4.47	12.11	1.47	0.05
Komal Spinach	7.32	3.68	10.97	1.66	0.04
Palak All Green	5.04	1.38	6.40	2.44	0.02
Spinach Solan Harit	6.30	2.95	9.22	2.33	0.02
Green Flavour	4.99	3.64	8.59	2.20	0.04
Ananya Green	5.67	2.40	8.04	2.15	0.03
Samag Star	5.02	2.95	7.93	2.49	0.13
Spinach Green Hara Sona	5.69	3.19	8.85	1.37	0.09
Palak Beej	7.01	4.2	11.17	1.47	0.03
All Green Composite	6.43	4.02	10.41	1.85	0.06
Local Selection 1	6.56	4.13	10.66	1.97	0.04
Local Selection 2	7.24	4.13	11.33	1.79	0.05
Local Selection 3	7.51	4.06	11.52	1.50	0.07
Palak Harita	4.50	3.26	7.73	2.31	0.07
Pusa Harit (standard check)	6.43	4.15	10.54	1.65	0.09
Overall mean	5.99	3.33	9.29	1.91	0.07
Range	3.54-7.72	1.21-4.53	4.91-12.15	1.21-2.64	0.02-0.23
$CD_{0.05}$	1.27	0.80	1.09	0.23	0.01
CV	12.83	14.55	7.12	7.36	10.87

Singh et al (2008) also reported high variation and range among different morphological traits of *S oleracea*. Varalakshmi and Devraju (2010) and Reddy et al (2014) also reported wide range of estimates for yield per plant in Indian Spinach. Yosefi et al (2010) also reported significant differences among genotypes for phenolic content in *S oleracea*.

CONCLUSION

The study revealed significant genetic variability among twenty spinach genotypes for a wide range of morphological, agronomic and biochemical traits. This variability provides a strong foundation for breeding and selection strategies aimed at improving yield and nutritional quality.

Genotypes like Ananya Green, Komal Spinach and Supriya demonstrated superior performance in key growth and yield parameters, while All Green and selected local varieties excelled in chlorophyll and phenolic content, indicating better photosynthetic efficiency and antioxidant potential.

The stable expression of traits such as petiole diameter and days to first cutting further reinforced their reliability for consistent performance across environments. The findings emphasized the importance of multi-trait selection in developing superior, high-yielding and nutritionally enriched spinach cultivars suitable for north Indian agro-climatic conditions.

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