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Morphological Characterization-based Optimal Trait Selection for Improving Yield and Stability of Soybean (*Glycine max* L. Merrill)

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ABSTRACT

The present investigation was convened during *kharif,* 2022 (July–October), *rabi*–summer, 2023 (January–May) and *kharif,* 2023 (July–October) at J.N.K.V.V., Jabalpur, Madhya Pradesh, India to characterize 165 diverse soybean germplasm lines in pursuance of DUS (Distinctness, Uniformity, and Stability) guidelines focusing on integrating optimal morphological traits to pre-fine soybean crop improvement. The study revealed significant variation among soybean genotypes. The hypocotyl color, controlled by a monogenic trait, was found in 77 genotypes, closely associated with violet flower color, whereas non-pigmented hypocotyls present in 88 genotypes were linked to white flowers. Growth habits were categorized as determinate (59), semi-determinate (103), and indeterminate (3), demonstrating that semi-determinate genotypes offer balanced resource allocation and reduced lodging. Most genotypes displayed medium flowering time (159) and medium plant height (134). Leaf shape was predominantly pointed ovate (121), with lanceolate leaves associated with higher number of seeds^{-1} pod. The presence of dark green leaves in 108 genotypes indicated higher chlorophyll content and enhanced photosynthetic efficiency to strengthen plant type. Semi-erect growth habit was prevalent in 152 genotypes, providing better soil coverage and moisture retention, while 13 genotypes showed erect growth. Pod pubescence was observed in 106 genotypes, offering protection against pests. These traits are found stable across the environment and may be used as an identification key for different varieties and donor germplasm lines.

KEYWORDS: DUS guidelines, morphological traits, monogenic trait, soybean germplasm

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1. INTRODUCTION

The soybean (*Glycine max* (L.) Merrill) that originated from East Asia (Central China) is the most valuable global crop (Sileshi, 2019, Amrate, 2024). Soybean belongs to the family *Fabaceae* and subfamily *papilionaceae* (Mehra et al., 2020, Upadhyay et al., 2020). Earlier the wild soybean (*Glycine soja*) has been domesticated during the Shang Dynasty 1700 to 1100 B.C (Hymowitz, 2004). Soybean also known as the golden bean, super legume, crop of the world, or miracle bean due presence of enormous nutritive values and applications (Agarwal et al., 2013, Thakur et al., 2022, Amrate et al., 2020). The seed of soybean is prominent source of protein (40–42%), edible oil (18–22%), carbohydrate, amino acids, fatty acids, minerals (Ca and P), vitamins (e.g. A, B, C and D) and antioxidants (Uikey et al., 2022; Banerjee et al., 2023; Amrate et al., 2024). More than half of the soybeans farmed are used to produce oil, with the remaining utilized to produce soymeal for animal feed and nutritious edible cuisine (Malek et al., 2014, Olías et al., 2023). In addition to conventional animal feed and industrial purposes, soybean crops are used to make soy milk, miso, tofu, protein, and tempeh (Rizzo and Baroni, 2018, Olías et al., 2023).

The crop is mostly grown in Brazil (39.17 mha), the United States (34.94 mha), Argentina (16.47 mha), and India (12.10 mha). In India, soybean is introduced from USA for the conduction of trial during 1960s, thereafter, in 1963 it started growing in the farmers field and now, the country has assumed the tag of one of the fifth largest producer of soybean in the world (Agarwal et al., 2013; Sagarika et al., 2023; Amrate, 2024). In India, the area under soybean farming in 2022–23 was 12.09 mha. Madhya Pradesh (50.18 lakh ha) has the highest cultivated area in the India, followed by Maharashtra (49.10 lakh ha), Rajasthan (11.51 lakh ha), Karnataka (4.43 lakh ha), Gujarat (2.22 lakh ha), and Telangana (1.75 lakh ha) (Anonymous, 2024).

To meet their specific needs, plant breeders, seed inspectors, researchers, and other clientele characterize a variety (Painkra et al., 2019). Multiple superior genotypes must be managed simultaneously in a crop improvement programme (Upadhyay et al., 2022). There are several possibilities for mixing and duplicating germplasm lines (Jawarkar et al., 2023, Ullah et al., 2024). The presence of genetic variation within the population of that species is a prerequisite of any crop improvement programme (Alpna et al., 2015). To evaluate genetic diversity, a comprehensive database of distinctive characteristics is necessary. These databases can be constructed through morphological descriptors (Pachori et al., 2023). Because the environment less influences qualitative traits and exhibits consistent expression, morphological description has proven to be a successful and reliable approach for plant germplasm identification (Shilpashree et al., 2021) and categorization, breeding material selection, and genetic diversity identification (Ramteke et al., 2015, Anand et al., 2024, Banerjee et al., 2022).

The Indian government designated its own sui generis system under the Protection of Plant Varieties and Farmers Rights Act 2001, which attempts to protect plant varieties based on distinctiveness, uniformity, and stability (DUS) (Singh et al., 2021, Thakur et al., 2022). In soybeans and other crops, varieties and genotypes are defined visually using descriptors based on DUS (Barela et al., 2022, Painkra et al., 2019). Considering these deliberations, an analysis was conducted to characterize the various soybean germplasm lines using morphological descriptors, with the ultimate objective of assisting in the selection and more effective utilization of this germplasm in breeding programmes.

2. MATERIALS AND METHODS

2.1. Experimental details

A field experiment was carried out in *Kharif* 2022 (July–October), *rabi-summer* 2023 (January–May), and *kharif,* 2023 (July–October) in JNKVV Jabalpur, Madhya Pradesh, India. It thoroughly evaluated 165 diverse soybean germplasm lines, comprising five checks (JS 20-34, JS20-69, JS20-98, JS 20-116, and NRC 138). The experimental materials were obtained from the All India Coordinated Research Project (AICRP) on Soybean, Department of Plant Breeding and Genetics, JNKVV, Jabalpur, and the Indian Institute of Soybean Research, Indore (Madhya Pradesh).

In an Augmented Complete Block Design (ACBD), each genotype was planted in two rows of three meters, with a row-to-row spacing of 40 cm and a plant-to-plant distance of 5 cm. The experimental location contained uniform landscape medium black soil with a pH of 7.5 and was devoid of waterlogging. Plant-to-plant spacing was maintained by removing the additional plant 10 days after seeding. All prescribed packages and practices were employed throughout the growing phase to care for and nourish the plants.

2.2. Observations

Observations were recorded for various traits including hypocotyl: anthocyanin pigmentation, plant: growth type, plant: days to 50% flowering, leaf: shape, leaf: colour, plant: growth habit, flower: colour, plant: height (cm), pod: pubescence, pod: pubescence colour, pod: colour, plant: days to maturity, seed: size (100 seeds weight), seed: shape, seed: colour, seed: hilum colour, and seed: cotyledon colour. These observations were made as per the DUS guideline given by The Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA), Govt. of India, New Delhi (Table 1) (Anonymous, 2009, Ramteke et al., 2012, Banerjee et al., 2022). Plant: Days to 50% flowering, Plant: Height (cm), Plant: Days to maturity, Seed: Size (100 seeds weight) were recorded only in *kharif*, 2022 and *kharif*, 2023, while the rest of the traits were recorded in all three seasons.

3. RESULTS AND DISCUSSION

Phenotypic characterization as per DUS (Distinctness, Uniformity, and Stability) guidelines and frequency distribution of specific descriptors revealed colossal variation in genotypes for different classes of descriptors (Table 2). The trait of hypocotyl colour (anthocyanin pigmentation) is considered a distinct trait because of monogenic control and was present in 77 genotypes and absent in 88 (Figure 3, 4). This trait was advantageous in the early detection of genotypes purity and was closely associated with the flower colour (Figure 1, 2). All the pigmented genotypes had violet flowers, and white flowers were seen in genotypes with non-pigmented hypocotyl (Table 3).

Table 1: Essential characters along with descriptor

Sl. No.	Characteristics	Expression/States and Note/ Score		
1.	Hypocotyl: Anthocyanin pigmentation	Absent (1)		Present (9)
2.	Plant: Growth type	Determinate (1)	Semi-determinate (2)	Indeterminate(3)
3.	Plant: Days to 50% flowering	Early (≤35 days) (3)	Medium (36 to 45 days) (5)	Late (>45 days) (7)
4.	Leaf: Shape	Lanceolate (1)	Pointed ovate (2)	Rounded ovate (3)
5.	Leaf: Colour	Green (1)		Dark green (2)
6.	Plant: Growth habit	Erect (1)		Semi-erect (2)
7.	Flower: Colour	White (1)		Purple (2)
8.	Plant: Height (cm)	Short (≤40) (3)	Medium (41–60) (5)	Tall(>60) (7)
9.	Pod: Pubescence	Absent (1)		Present (9)
10.	Pod: Pubescence colour	Grey (1)		Tawny (Brown) (2)
11.	Pod: Colour	Yellow (1)	Brown(2)	Black (3)
12.	Plant: Days to maturity	Early (≤95 days) (3)	Medium (96–105 days) (5)	Late(>105 days) (7)
13.	Seed: Size (100 seeds weight)	Small (≤10.0 g) (3)	Medium (10.1–13.0 g) (5)	Large (>13.0 g) (7)
14.	Seed: Shape	Spherical (1)		Elliptical (2)
15.	Seed: Colour	Yellow (1)	Yellow green (2)	Green (3)
16..	Seed: Hilum colour	Grey (2)	Brown (3)	Black (4)
17.	Seed: Cotyledon colour	Yellow (1)		Green(2)

Out of 165 genotypes, growth habits were categorized as determinate (59), semi-determinate (103) and three were indeterminate (GW-75, KDS 1201, RSC 11-20). Determinate genotypes cease vegetative growth when the reproductive stage is initiated to preventing source limitation in the crop. The semi-determinate type genotype shows balanced growth pattern, continuing vegetative growth while entering the reproductive stage allows better resource allocation to both vegetative and reproductive stages give higher yield and avoid lodging issues found in indeterminate types.

Flowering time was observed as early in 4 genotypes, Medium in 159, and late flowering in 2 genotypes providing valuable insights for breeding programs, aiding in the selection of genotypes with desirable flowering traits. The observation of three types of leaf shapes, i.e., pointed ovate (121), rounded ovate (21), and lanceolate (23), is noteworthy (Figure 12, 13, 14). The finding of four-seeded pods in genotypes with a lanceolate leaf shape, along with an increase in the ratio of three-seeded pods, suggesting a potential yield advantage.

The presence of dark green leaves in the majority of genotypes (108) is an indicative of higher chlorophyll content and, consequently greater photosynthetic efficiency, which is a desirable trait for crop productivity. Growth habit was predominantly semi-erect in the majority of the genotypes (152), and only 13 genotypes show erect growth habit. Semi-erect-type plants cover the soil more efficiently

Table 2: Morphological characterization of soybean genotypes as per DUS guideline

Sl. No.	Germplasm line	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1.	AS 24	9	1	7	2	1	2	2	5	1		3	5	5	2	1	3	1
2.	AUS 32	9	2	7	2	1	2	2	5	9	2	1	3	3	2	1	3	1
3.	AMS 56	9	2	7	1	2	2	2	5	1		3	5	5	1	1	4	1
4.	AMS 77	1	2	7	2	1	2	1	5	9	1	2	5	3	2	1	3	1
5.	AMS 77-3-6	9	2	7	2	2	2	2	5	9	2	2	3	5	2	1	4	1
6.	AMS 264	9	1	7	1	2	2	2	5	1		3	5	5	1	1	3	1
7.	AMS 269	9	1	7	1	2	2	2	5	1		3	5	5	1	2	3	1
8.	AMS 358	9	1	7	1	2	2	2	5	1		3	5	5	1	2	3	1
9.	AMS 475	9	1	7	1	2	2	2	5	1		3	5	5	1	1	4	1
10.	AMS 4873	9	1	7	1	2	2	2	5	1		2	5	5	2	1	4	1
11.	AUKS 199	9	2	7	2	2	2	2	5	9	2	3	3	3	2	1	4	1
12.	AUKS 203	9	2	7	2	2	2	2	5	9	2	2	3	5	2	1	4	1
13.	AUKS 206	9	1	7	2	2	2	2	5	9	2	2	3	5	2	1	4	1
14.	AUKS 207	9	2	7	2	2	2	2	5	9	2	1	3	5	2	1	4	1
15.	AUKS 218	9	2	7	2	1	2	2	3	9	1	1	3	3	2	1	3	1
16.	AMS MB-5-19	1	1	7	2	1	2	1	5	9	1	2	5	5	2	1	3	1
17.	AMS 2014-1	9	1	7	2	2	2	2	3	1		2	5	5	2	1	3	1
18.	B 327	9	2	7	2	1	2	2	5	9	2	1	3	3	2	3	3	1
19.	B 1667	9	2	7	2	2	2	2	5	9	1	2	5	3	2	2	3	1
20.	BAUS 116	1	1	7	2	1	2	1	5	9	2	2	5	3	2	2	3	1
21.	CAT 489A	9	2	7	2	2	2	2	5	9	1	2	3	5	2	3	3	2
22.	DCB 137	1	2	7	2	2	2	1	5	9	1	2	5	3	1	1	3	1
23.	DS 3104	9	2	7	2	2	2	2	5	9	2	2	3	3	2	1	3	1
24.	DS 3109	1	1	7	2	1	2	1	5	1		2	7	5	2	1	3	1
25.	DS 3124	9	1	7	2	2	2	2	3	1		3	5	3	2	1	3	1
26.	ERS 1344	1	1	7	2	1	1	1	5	9	2	3	5	5	2	1	3	1
27.	EC 481571	9	2	7	2	2	2	2	5	9	2	1	3	3	2	2	3	1
28.	EC 389149	9	2	7	2	2	2	2	5	9	2	1	3	3	2	2	3	1
29.	EC 350664	9	1	7	2	1	2	2	5	9	2	2	5	5	2	1	4	1
30.	EC 313915	9	2	7	2	1	2	2	3	9	2	3	3	3	2	3	3	2
31.	EC 389179 B	9	2	7	2	1	2	2	5	9	2	2	5	5	2	1	4	1
32.	G 11	1	2	7	2	1	2	1	5	9	1	2	5	5	2	1	3	1
33.	G 448	1	2	7	2	2	2	1	7	9	2	3	5	5	2	1	3	1
34.	GW 50	9	1	7	2	2	2	2	5	1		3	5	5	2	1	4	1
35.	GW 70	1	2	7	2	1	2	1	5	9	2	1	5	3	2	2	4	1
36.	GW 75	1	3	7	2	2	2	1	5	1		2	5	7	1	1	3	1
37.	GW 76	9	2	7	2	1	2	2	5	1		3	3	5	2	1	3	1
38.	GW 85	1	2	7	2	2	2	1	5	9	2	2	5	3	1	1	3	1
39.	GW 89	9	2	7	2	2	2	2	5	9	2	2	3	3	2	3	3	2
40.	GW 108	9	2	7	2	1	2	2	5	9	2	2	5	5	2	3	3	2

Table 2: Continue...

Sl. No.	Germplasm line	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
41.	GW 152	1	2	7	2	1	2	1	7	9	2	1	5	5	2	1	3	1
42.	GW 175	1	2	7	2	1	2	1	5	1		2	5	5	2	1	3	1
43.	JS 20-20	9	2	7	2	2	2	2	3	9	2	1	3	5	2	1	4	1
44.	JS 20-50	1	2	7	2	1	2	1	5	9	2	2	5	7	2	1	3	1
45.	JS 20-78	1	2	7	2	2	2	1	5	9	1	2	5	5	2	1	3	1
46.	JS 20-86	1	2	7	2	2	2	1	5	1		2	5	5	2	1	3	1
47.	JS 20-96	1	2	7	2	1	2	1	5	9	2	1	5	3	2	2	4	1
48.	JS 21-05	1	2	7	2	2	2	1	5	9	2	2	5	5	2	1	3	1
49.	JS 21-06	9	2	7	2	2	2	2	5	9	2	2	3	5	2	1	4	1
50.	JS 21-08	1	1	7	1	2	1	1	5	9	2	3	5	5	2	1	4	1
51.	JS 21-13	1	2	7	2	2	2	1	5	9	2	1	5	3	2	1	4	1
52.	JS 21-71	1	2	7	2	2	2	1	5	9	1	2	5	5	2	1	3	1
53.	JS 21-74	9	2	7	3	2	2	2	5	1		3	3	5	2	1	4	1
54.	JS 21-75	9	2	7	3	2	2	2	5	1		3	3	5	2	1	3	1
55.	JS 21-78	1	2	7	1	2	2	1	5	1		1	3	5	2	1	4	1
56.	JS 22-01	1	2	7	2	1	2	1	5	9	2	1	5	5	2	1	3	1
57.	JS 22-02	9	2	7	2	2	2	2	5	1		2	5	5	2	1	4	1
58.	JS 22-03	9	2	7	2	1	2	2	5	9	2	2	5	5	2	1	4	1
59.	JS 22-04	9	2	7	3	2	2	2	5	1		3	3	5	2	1	3	1
60.	JS 22-05	1	2	7	1	2	2	1	5	1		1	3	3	2	1	3	1
61.	JS 22-07	1	2	7	2	1	2	1	5	9	2	2	5	5	2	1	3	1
62.	JS 22-08	1	2	7	2	1	2	1	5	9	2	2	5	5	2	1	3	1
63.	JS 22-09	1	2	7	2	2	2	1	5	9	2	3	5	5	2	1	3	1
64.	JS 22-12	9	1	7	3	2	2	2	5	1		2	3	5	1	1	4	1
65.	JS 22-13	1	1	7	2	1	2	1	5	9	2	2	5	7	1	1	3	1
66.	JS 22-14	9	1	7	2	2	2	2	5	1		2	5	5	2	1	3	1
67.	JS 22-15	1	1	7	2	2	1	1	5	9	2	2	5	5	2	1	3	1
68.	JS 22-16	1	2	7	2	2	2	1	5	9	2	2	3	5	1	1	4	1
69.	JS 22-17	1	1	7	2	1	2	1	5	9	2	2	5	5	2	1	3	1
70.	JS 22-18	9	1	7	2	2	2	2	3	1		2	3	5	2	1	4	1
71.	JS 22-21	1	2	7	1	1	2	1	5	9	2	1	3	5	1	1	4	1
72.	JS 22-30	9	1	7	3	2	2	2	5	1		2	5	3	2	1	4	1
73.	JS 22-32	9	1	7	2	2	2	2	5	9	2	2	5	5	2	2	4	1
74.	JS 22-35	1	1	7	1	2	1	1	5	9	2	1	3	5	1	1	4	1
75.	JS 22-38	1	2	7	2	1	2	1	5	9	2	3	5	5	2	1	3	1
76.	JS 22-39	9	2	7	2	2	2	2	5	9	2	2	3	3	2	2	3	1
77.	JS 22-41	9	1	7	3	2	2	2	3	1		2	3	5	2	1	4	1
78.	JS 22-43	9	1	7	2	2	2	2	3	1		1	3	5	2	1	4	1
79.	JS 22-44	9	1	7	2	1	2	2	3	9	2	3	3	5	2	2	4	1
80.	JS 22-48	1	2	7	2	2	2	1	5	9	2	2	5	7	2	1	4	1

Table 2: Continue...

Sl. No.	Germplasm line	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
81.	JS 22-49	9	2	7	3	2	2	2	5	9	1	2	3	3	2	1	4	1
82.	JS 22-53	1	1	7	2	1	2	1	5	9	1	2	5	7	1	2	3	1
83.	JS 23-02	1	1	7	2	2	2	1	5	9	2	2	3	5	2	1	3	1
84.	JS 23-03	9	2	7	2	2	2	2	5	1		1	3	5	2	1	4	1
85.	JS 23-05	1	1	7	2	2	2	1	5	9	1	1	3	5	1	1	3	1
86.	JS 23-06	1	1	7	1	2	2	1	5	9	2	1	3	3	1	1	4	1
87.	JS 23-07	9	1	7	2	1	2	2	3	9	2	2	5	3	2	1	4	1
88.	JS 23-09	9	2	7	2	2	2	2	5	1		2	3	5	2	1	4	1
89.	JS 23-10	9	2	7	3	2	2	2	5	1		3	3	5	1	1	4	1
90.	JS 24-23	9	1	7	1	2	2	2	5	1		3	3	5	1	1	4	1
91.	JS 24-25	1	1	7	1	2	2	1	5	9	1	3	3	5	2	1	3	1
92.	JS 24-26	1	1	7	2	2	2	1	5	9	2	2	5	5	1	2	3	1
93.	JS 24-27	1	1	7	2	2	2	1	5	9	2	2	5	5	2	1	3	1
94.	JS 24-28	9	2	7	2	2	2	2	5	1		1	5	5	2	1	4	1
95.	JS 24-29	1	2	5	2	2	2	1	5	9	2	1	5	7	2	1	3	1
96.	JS 24-30	9	2	7	2	2	2	2	5	9	2	3	5	7	2	1	4	1
97.	JS 24-32	1	2	7	2	2	2	1	5	1		3	5	5	2	1	3	1
98.	JS 24-33	9	2	7	2	2	2	2	5	1		2	3	5	2	1	4	1
99.	JS 24-34	9	2	7	2	2	2	2	5	1		2	3	5	2	2	4	1
100.	JSM 126	1	2	7	2	1	2	1	7	9	2	2	5	5	1	2	3	1
101.	JSM 230	1	2	7	2	2	2	1	5	9	2	2	5	5	2	1	4	1
102.	JSM 242	1	2	7	2	2	2	1	5	1		2	5	5	2	1	4	1
103.	JSM 283	9	2	7	3	1	2	2	5	1		2	5	5	2	1	3	1
104.	KDS 32	9	2	7	2	2	2	2	5	9	1	3	3	5	1	1	3	1
105.	KDS 1201	9	3	7	2	2	2	2	5	1		2	5	5	2	2	3	1
106.	MAUS 791	9	1	7	1	2	2	2	5	1		3	3	5	1	1	4	1
107.	MACS 1370	9	2	7	2	2	2	2	5	1		2	5	5	2	1	4	1
108.	NRC 125	9	2	7	3	2	2	2	5	9	2	2	5	5	2	2	4	1
109.	NRC 130	1	2	7	2	2	2	1	5	9	2	2	3	5	2	1	3	1
110.	NRC 137	1	2	7	2	1	2	1	5	9	2	2	5	5	1	2	3	1
111.	NRC 150	1	2	7	3	2	2	1	3	9	2	2	3	5	2	1	3	1
112.	NRC 166	9	2	7	1	2	2	2	5	1		2	3	5	2	2	3	1
113.	NRC 178	9	1	7	3	2	2	2	3	1		3	3	5	1	1	3	1
114.	NRC 181	1	2	3	3	1	2	1	5	9	2	2	3	5	2	1	4	1
115.	NRC 186	9	2	7	3	2	2	2	5	1		2	5	3	2	2	4	1
116.	NRC 189	1	2	7	3	2	2	1	5	1		1	5	3	2	1	4	1
117.	NRC 190	9	2	7	3	2	2	2	5	1		2	5	3	2	1	4	1
118.	NRC 192	1	2	7	2	2	2	1	5	1		2	3	5	2	2	4	1
119.	NRC 196	1	2	7	2	2	2	1	5	9	2	2	5	5	2	1	4	1
120.	NRC 201	1	2	7	2	2	2	1	5	9	2	2	5	3	2	1	3	1

Table 2: Continue...

Sl. No.	Germplasm line	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
121.	NRC SL-1	9	2	7	3	2	2	2	5	1		2	5	3	2	1	3	1
122.	PS 1092	1	2	7	2	2	2	1	5	9	2	2	5	5	2	2	4	1
123.	PS1569	1	1	7	1	2	2	1	5	9	2	3	3	5	1	1	4	1
124.	PS 1589	9	1	7	2	1	2	2	3	9	2	2	3	3	2	1	4	1
125.	PS 1611	9	1	7	2	2	2	2	5	1		1	5	5	2	2	4	1
126.	PS 1613	1	2	7	2	2	2	1	5	9	2	2	3	5	2	1	3	1
127.	PS 1641	1	2	7	2	1	2	1	3	9	2	1	5	3	2	1	3	1
128.	PS 1660	1	2	7	2	1	2	1	5	9	2	1	5	5	2	2	3	1
129.	PS 1661	1	2	7	2	1	2	1	5	9	2	1	5	3	2	2	3	1
130.	PS 1664	1	2	7	2	1	2	1	5	9	2	1	5	5	2	1	4	1
131.	PS 1670	1	1	7	1	2	1	1	5	1		2	5	5	2	1	3	1
132.	PS 1675	1	2	7	2	1	1	1	5	9	2	2	3	3	2	1	3	1
133.	PS 1682	1	1	7	2	1	1	1	3	9	2	1	5	3	2	1	3	1
134.	RSC 9	1	2	5	2	1	2	1	5	9	2	2	7	3	2	2	4	1
135.	RVS 13-15	9	1	7	1	1	1	2	5	1		3	5	5	1	1	4	1
136.	RVS 13-20	1	1	7	1	1	1	1	5	1		3	3	5	1	1	4	1
137.	RSC 11-07	9	2	7	2	1	2	2	5	1		3	5	5	2	2	4	1
138.	RSC 11-20	1	3	7	2	1	2	1	5	1		2	5	3	2	1	4	1
139.	RVS 2006-4	9	1	7	2	2	2	2	3	9	2	2	5	5	2	1	3	1
140.	RVS 2011-1	1	1	7	2	2	2	1	5	9	2	3	3	7	2	1	3	1
141.	RVS 2011-10	1	1	7	2	2	2	1	3	9	2	1	5	5	2	1	3	1
142.	RVS 2011-12	1	1	7	3	2	2	1	5	1		3	5	3	2	2	4	1
143.	RVSM 2012-4	1	1	7	2	1	2	1	3	9	2	2	5	3	2	1	4	1
144.	RVS 2012-10	1	1	7	1	2	1	1	5	1		2	5	5	2	2	4	1
145.	RVS 2012-19	1	1	7	1	1	1	1	5	9	2	2	5	7	2	1	4	1
146.	RVSM 2012-11	9	1	7	3	2	2	2	3	1		3	3	3	2	1	4	1
147.	SL 96	9	2	7	2	2	2	2	3	1		2	3	5	2	1	4	1
148.	SL 955	1	1	7	2	1	1	1	3	9	1	1	5	3	1	2	3	1
149.	SL 1213	1	1	7	2	1	1	1	3	9	1	3	5	3	1	2	4	1
150.	VLS 58	1	2	7	2	1	2	1	5	9	2	2	5	5	2	1	4	1
151.	VLS 89	1	2	3	2	2	2	1	5	9	2	1	5	5	2	1	3	1
152.	VLS 94	1	2	7	2	1	2	1	5	9	1	1	5	5	2	1	3	1
153.	JS 25-46	1	1	7	2	2	2	1	3	9	2	2	5	7	1	1	4	1
154.	JS 24-37	9	1	7	1	2	2	2	3	9	2	1	3	5	2	1	4	1
155.	JS 25-48	1	1	7	2	2	2	1	5	9	2	1	3	5	2	1	4	1
156.	JS 25-50	9	2	7	2	2	2	2	3	9	2	2	5	5	2	1	4	1
157.	JS-25-53	1	2	7	2	2	2	1	5	9	2	1	5	5	2	1	4	1
158.	JS 25-52	9	2	7	2	2	2	2	5	9	2	1	5	5	2	1	4	1
159.	JS 25-51	9	2	7	2	2	2	2	3	9	2	1	3	5	2	1	4	1
160.	JS 25-59	1	2	7	2	1	2	1	5	9	2	2	5	5	2	1	4	1

Table 2: Continue...

Sl. No.	Germplasm line	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
161.	JS 20-34 (Check)	1	1	3	3	2	2	1	3	1		1	3	5	2	1	4	1
162.	JS 20-69 (Check)	1	2	7	2	1	2	1	5	9	2	2	5	5	2	1	4	1
163.	JS 20-98 (Check)	1	2	7	2	1	2	1	5	9	1	1	5	5	1	2	4	1
164.	JS 20-116 (Check)	1	2	7	3	1	2	1	5	1		2	5	3	1	1	4	1
165.	NRC-138 (Check)	1	1	3	2	2	2	1	3	9	2	2	3	5	2	1	3	1

A: Hypocotyl: Anthocyanin pigmentation; B: Plant: Growth type; C: Plant: Days to 50% flowering; D: Leaf: Shape; E: Leaf: Colour; F: Plant: Growth habit; G: Flower: Colour; H: Plant: Height (cm); I: Pod: Pubescence; J: Pod: Pubescence colour; K: Pod: Colour; L: Plant: Days to maturity; M: Seed: Size (100 seeds weight); N: Seed: Shape; O: Seed: Colour; P: Seed: Hilum colour; Q: Seed: Cotyledon colour

and reduce moisture loss due to evaporation during dry spells as well as suppress the weed growth whereas erect-type plants show better air circulation and light penetration may be perform well under high crop stand conditions.

Most of the genotypes were of medium plant height (134), some were of short plant height (28), and only two genotypes were of small. The pods of 106 genotypes were pubescent (88-tawny hair and 18-grey hair), and the rest of the 59 genotypes were glabrous type, i.e. devoid of trichrome on their pods (Figure 5, 6, 7). Pubescence may act as a physical barrier to protect leaves from excessive light, maintaining higher photosynthetic rates (An et al., 2023). Pubescent pods and stem are preferred host for lepidopterans but show non-preference by whitefly, aphids and jassids (Hulburt et al., 2004, Baldin et al. 2017, Li et al., 2022).

Eighty nine genotypes exhibited brown pod color, forty were yellow and only 36 genotype of black pod coloration. Four type of maturity groups are their i.e. Early (63), Medium (100), and late (2). Small seed sizes are present in 40 genotypes, and medium and large seed sizes are present in 113 and 10 genotypes only. Early genotypes can escape from dry spells occurred due to the early withdrawal of monsoon and allow for subsequent crop sowing in residual soil moisture, whereas late genotypes offer a high yield potential.

Seed Shape are found elliptical in the majority of genotypes, only 32 genotypes are of spherical shape (Fig. 10, 11). Seed coat colour was recorded green in five genotypes

Distinguishing morphological traits of soybean

Flower Colour

Figure 1: Purple

Figure 2: White

Hypocotyl: Anthocyanin Colouration

Figure 3: Present

Figure 4: absent

Pod: Pubescence

Figure 5: Grey

Figure 6: Tawny (Brown)

Figure 7: Glabrous pod

Seed hilum Colour

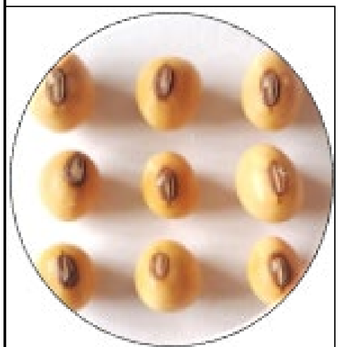
Figure 8: Brown


Figure 9: Black

SEED: Shape


Figure 10: Spherical


Figure 11: Elliptical

Leaf Shape


Figure 12: Pointed Ovate


Figure 13: Lanceolate


Figure 14: Rounded Ovate

Table 3: Frequency distribution of morphological trait

Sl. No.	Characteristics	Expression/States	Genotype frequency	Percentage contribution
1.	Hypocotyl: Anthocyanin pigmentation	Absent	88	53.33
		Present	77	46.66
2.	Plant: Growth type	Determinate	59	35.76
		Semi-determinate	103	62.42
		Indeterminate	03	1.82
3.	Plant: Days to 50% flowering	Early (≤35 days)	04	2.42
		Medium (36 to 45 days)	159	96.36
		Late (>45 days)	02	1.21
4.	Leaf: Shape	Lanceolate	23	13.94
		Pointed ovate	121	73.33
		Rounded ovate	21	12.73
5.	Leaf : Colour	Green	57	34.54
		Dark green	108	65.45
6.	Plant: Growth habit	Erect	13	7.88
		Semi-erect	152	92.12
7.	Flower: Colour	White	88	53.33
		Purple	77	46.66

Table 3: Continue...

Sl. No.	Characteristics	Expression/States	Genotype frequency	Percentage contribution
8.	Plant: Height (cm)	Short (≤40)	28	16.97
		Medium (41–60)	134	81.21
		Tall (>60)	3	1.82
9.	Pod: Pubescence	Absent	59	35.76
		Present	106	64.24
10.	Pod: Pubescence colour	Grey	18	10.91
		Tawny (Brown)	88	53.33
11.	Pod: Colour	Yellow	40	24.24
		Brown	89	53.94
		Black	36	21.82
		Early (≤95 days)	63	38.18
		Medium (96–105 days)	100	60.61
		Late (>105 days)	2	1.21
13.	Seed: Size (100 seeds weight)	Small (≤10.0 g)	42	25.45
		Medium (10.1–13.0 g)	113	68.48
		Large (>13.0 g)	10	6.06
14.	Seed: Shape	Spherical	32	19.39
		Elliptical	133	80.61
15.	Seed: Colour	Yellow	128	77.58
		Yellow green	32	19.39
		Green	5	3.03
16.	Seed: Hilum colour	Red Brown	7	4.24
		Brown	74	44.85
		Black	84	50.91
17.	Seed: Cotyledon colour	Yellow	161	97.58
		Green	4	2.42

(B-327, CAT-489A, EC 313915, GW-89, and GW-108), yellowish-green in 32 and yellow in 128 genotypes. Black hilum colour was present in 84 genotypes, brown in 81 genotypes (Figure 8, 9). Yellow seed cotyledon colour was present among 97.58% of genotypes and green in 2.42% (CAT-489A, EC 313915, GW-89, and GW-108). Yellow cotyledon soybeans are commonly used commercially due to their high oil content and pleasant flavour and colour in the extracted oil (Azam et al., 2024). Similar, characterization pattern was adopted by Ramteke et al. (2012), Malek et al. (2014), Verma et al. (2015), Ramteke et al. (2015), Painkra et al. (2019), Singh et al. (2021), Thakur et al. (2022), Barela et al. (2022), Banerjee et al. (2022), Jawarkar et al. (2023).

4. CONCLUSION

The phenotypic characterization of 165 genotypes revealed significant genetic diversity in traits such as hypocotyl and flower color, growth habits, leaf shapes, and pod characteristics. Hypocotyl and flower color, lanceolate leaf shape and four seeded pods was closely associated. The optimal trait combination includes semi-determinate growth type, semi-erect growth habit, lanceolate leaf shape, Dark green leaves, yellow seed cotyledons, pubescent plant and medium flowering time with early maturity. By combining these valuable traits, breeders can develop high-yielding soybean varieties.

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