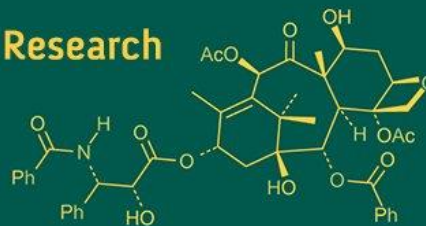


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Morphological characterization and phenotypic variability among *Basella* genotypes

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Abstract

The present investigation was carried out to evaluate morphological diversity and distinctness among 24 genotypes of *Basella* (*Basella alba* L. and *Basella rubra* L.) using standardized, descriptor-based scoring under field conditions at Raipur, Chhattisgarh. Observations were recorded on leaf, stem, vine growth, flowering, fruit and seed traits using visual assessment and numerical descriptor scales. Considerable variability was observed among genotypes for most of the characters studied. Leaf colour, stem pigmentation, petiole colour, midrib pigmentation, flower colour and mature fruit colour segregated the germplasm into two clear morphotypes: twelve genotypes exhibited green foliage, unpigmented stems and purple fruits, whereas twelve genotypes exhibited reddish-green foliage, pigmented stems and dark purple fruits. Leaf length, leaf width, stem thickness, internode length, petiole length and flower size showed a wide range of expression, whereas leaf margin type, stem surface texture, growth habit, flower arrangement, fruit shape and seed colour were monomorphic across all 24 genotypes. The study confirmed the usefulness of morphological descriptors in distinguishing *Basella* genotypes, demonstrated a strong association of vegetative and reproductive pigmentation traits, and identified promising material for varietal identification, germplasm registration and future breeding programmes.

Keywords: *Basella*, morphological descriptors, germplasm characterization, phenotypic diversity, leafy vegetable, betalain pigment, underutilized vegetable

Introduction

Basella spp., commonly known as Malabar spinach, Indian spinach, vine spinach, Ceylon spinach or climbing spinach, is an important leafy vegetable belonging to the family *Basellaceae*. The crop is widely cultivated in tropical and subtropical regions because of its rapid growth, heat tolerance, nutritional richness and adaptability to diverse environmental conditions. It is considered an important source of vitamins A and C, minerals, dietary fibre, carotenoids, flavonoids and antioxidant compounds that contribute significantly to nutritional security and human health (Chaurasiya *et al.*, 2021; Deshmukh and Gaikwad, 2014) [6, 7]. The crop is extensively cultivated in India, Southeast Asia, tropical Africa and several other tropical regions owing to its ability to thrive under high temperature and humid environmental conditions (Deshmukh and Gaikwad, 2014; Grubben and Denton, 2004) [7, 8]. The genus *Basella* has attracted considerable taxonomic and botanical interest because of the occurrence of distinct green- and red-pigmented forms commonly recognized as *Basella alba* L. and *Basella rubra* L. Linnaeus initially described these forms as separate species based mainly on stem colour, leaf morphology and pigmentation characteristics. However, several cytological, anatomical and protein profile studies suggested that both forms may represent variants within the same species complex (Roy *et al.*, 2010) [14]. Nevertheless, clear phenotypic differences in stem pigmentation, petiole colour, leaf coloration and fruit pigmentation continue to support their practical classification into *B. alba* and *B. rubra* during germplasm characterization and varietal identification studies (Deshmukh and Gaikwad, 2014) [7].

Morphologically, *Basella* is a succulent perennial twining herb characterized by fleshy stems, broad ovate to cordate leaves, clustered flowers and berry-like fruits. The crop exhibits substantial variation in vegetative and reproductive characters, including leaf colour, leaf size, leaf shape, stem pigmentation, growth habit, branching pattern, flowering behaviour and fruit colour (Anonymous, 2024) [3]. Such variability represents an important genetic resource for germplasm conservation, varietal development and crop improvement programmes. Morphological diversity among *Basella* genotypes has been reported in several studies, indicating the existence of distinct morphotypes and considerable phenotypic variability within cultivated populations (Adeniran *et al.*, 2023; Oyugi *et al.*, 2022) [5, 13]. Apart from its horticultural importance, *Basella* possesses remarkable medicinal and nutraceutical significance. The crop contains several biologically active compounds, including betalains, betacyanins, phenolic acids, flavonoids, carotenoids, β -sitosterol and lupeol, which exhibit antioxidant, antimicrobial, anti-inflammatory, anti-ulcer, hepatoprotective and antidiabetic activities (Deshmukh and Gaikwad, 2014; Kumar *et al.*, 2018) [7, 10]. The characteristic red-violet pigmentation observed in *B. rubra* is mainly attributed to betalain pigments, particularly betacyanins, which contribute to antioxidant activity and natural food-colouring properties (Kumar *et al.*, 2016) [11]. Furthermore, the leaves and fruits of *Basella* have been reported to possess high levels of bioactive compounds that enhance their nutritional and functional value (Chaurasiya *et al.*, 2021) [6].

Phenotypic characterization using standardized morphological descriptors remains one of the most reliable, economical and widely accepted approaches for evaluating plant genetic resources. Descriptor-based characterization provides a systematic framework for documenting qualitative and quantitative variation among genotypes and facilitates the identification of distinct, uniform and stable traits. Standardized descriptors such as leaf colour, leaf shape, leaf size, stem pigmentation, growth habit, flower colour, fruit colour and seed characteristics have been extensively used for germplasm characterization, varietal identification, genetic diversity studies and breeding programmes (IBPGR, 1988) [9]. Morphological descriptors continue to play a crucial role in preliminary evaluation and classification of vegetable germplasm because of their simplicity, effectiveness and direct field applicability.

Although several studies have emphasized the nutritional, medicinal and phytochemical significance of *Basella*, comprehensive descriptor-based evaluation of diverse *Basella alba* and *Basella rubra* genotypes remains limited, particularly under Indian agro-climatic conditions. Most available investigations focus primarily on phytochemical composition, antioxidant potential and medicinal properties, whereas comparatively less attention has been given to systematic phenotypic characterization and distinctness assessment using standardized morphological descriptors (Chaurasiya *et al.*, 2021; Deshmukh and Gaikwad, 2014) [6, 7]. Moreover, identification of genetically diverse genotypes possessing desirable morphological attributes is essential for germplasm conservation, varietal registration and future breeding programmes.

Therefore, the present investigation entitled “Morphological Characterization and Phenotypic Variability among *Basella* Genotypes” was undertaken to evaluate phenotypic

variability, assess distinct morphological traits and identify diverse genotypes using standardized descriptor scales. The information generated from this study may contribute towards germplasm characterization, varietal identification, conservation strategies and future crop improvement programmes in *Basella*.

Materials and Methods

Experimental site

The present investigation was conducted at the Research-cum-Instructional Farm, Department of Vegetable Science, College of Agriculture, Indira Gandhi Krishi Vishwavidyalaya, Raipur, Chhattisgarh, India, during the Rabi seasons of 2021-22 and 2022-23. Raipur is situated in the Chhattisgarh Plain agro-climatic zone between 21°14' N latitude and 81°38' E longitude at an altitude of approximately 289.6 m above mean sea level. The region experiences a tropical sub-humid climate characterized by hot summers and mild winters. During the experimental period, meteorological observations regarding temperature, relative humidity and rainfall were recorded from the university meteorological observatory.

Plant material

Twenty-four genotypes of *Basella*, comprising both *Basella alba* and *Basella rubra* types, were collected from different sources and maintained at the Department of Vegetable Science, IGKV, Raipur. The germplasm included twenty-four IGPB accessions (IGPB-2019-01 to IGPB-2019-03 and IGPB-2017-01 to IGPB-2017-21). All genotypes were grown under uniform cultural conditions and used for phenotypic characterization and descriptor-based evaluation.

Experimental design and crop establishment

The experiment was laid out in a Randomized Block Design (RBD) with three replications. Each genotype was grown in a separate plot under uniform cultural conditions. Seeds were directly sown in the field at a spacing of 50 cm × 50 cm between rows and plants, respectively. Twelve plants were maintained in each plot. Standard agronomic practices, including irrigation, weeding, intercultural operations and plant protection measures, were followed uniformly throughout the crop growth period to ensure proper crop establishment and healthy plant growth. The crop was maintained under uniform cultural conditions throughout the experimental period.

Morphological characterization

Morphological characterization of the *Basella* germplasm was carried out using standardized descriptor scales based on the IBPGR descriptors for leafy vegetables (IBPGR, 1988) [9] and modified descriptor guidelines suitable for *Basella* germplasm (Bogani, 2007) [4]. The observations for germplasm and varietal evaluation of leafy vegetable crops were also recorded following the NBPGR descriptors as described by Mahajan *et al.* (2000) [12]. These descriptors were used for the systematic recording and evaluation of important morphological traits of the *Basella* genotypes. Observations were recorded from five randomly selected healthy plants in each genotype and replication. The dominant expression of each character was considered for scoring, and disease-affected plant parts were excluded during characterization.

Leaf characters: The following leaf traits were recorded: leaf colour, leaf shape, leaf length, leaf width, leaf apex shape, leaf base shape, leaf margin type, leaf margin colour, leaf midrib pigmentation, leaf surface texture, leaf glossiness, leaf thickness, leaf succulence and leaf venation prominence.

Stem and petiole characters: The following stem and petiole traits were evaluated: stem colour, stem pigmentation intensity, stem shape, stem surface texture, stem thickness, internode length, petiole colour and petiole length.

Vine and growth characters: Growth-related traits were recorded during active vegetative growth, *i.e.*, growth habit. Flower characters: Observations on flowering were recorded at the peak flowering stage: flower colour, flower arrangement, flower size and flowering intensity. Fruit and seed characters: At physiological maturity, observations were recorded on mature fruit colour, fruit shape, and seed colour.

Descriptor-based scoring

Each qualitative and semi-quantitative trait was assigned a descriptor score according to predefined scales. Morphological descriptors were scored visually and categorized based on their intensity or expression level. Standardized numerical scales (1, 3, 5, 7 and 9) were used wherever applicable to represent low, intermediate and high expression of traits (Table 1).

Statistical analysis

The collected data were compiled and summarized using descriptive statistical methods. Frequency distribution and trait-wise variation among genotypes were used to assess phenotypic diversity. Genotypes were classified based on morphological descriptors and distinct phenotypic characteristics.

Results and Discussion

Descriptor-based scoring of 24 *Basella* genotypes revealed pronounced phenotypic variability for most of the qualitative and semi-quantitative traits studied. The frequency distribution of genotypes across descriptor states is summarized in Table 1. The traits grouped into three categories: (i) polymorphic diagnostic traits that clearly separated *B. alba* from *B. rubra* morphotypes, (ii) quantitative traits with graded expression (small, medium and large), and (iii) monomorphic traits common to the entire germplasm.

Leaf characters

Considerable variability was observed among genotypes for leaf colour, leaf size, leaf shape, leaf apex, leaf base and midrib pigmentation. Leaf colour showed three expression classes: light green (8.33%), dark green (41.67%) and reddish green (50.00%). The reddish-green class comprised all twelve genotypes IGPB-2017-10 to IGPB-2017-21, whereas the green classes comprised IGPB-2019-01 to IGPB-2019-03 and IGPB-2017-01 to IGPB-2017-09, along with two light-green genotypes (IGPB-2017-03 and IGPB-2017-04). Leaf shape varied between ovate (54.17%) and oval (45.83%), with no genotype expressing a cordate lamina. Reddish-green genotypes were uniformly ovate-

leaved, whereas the green genotypes were predominantly oval-leaved, indicating a consistent association between pigmentation and leaf outline in the present collection.

Leaf length and leaf width exhibited a wide range of expression across three graded classes. For leaf length, 25.00% of genotypes recorded small leaves (<8.5 cm), 25.00% medium leaves (8.5-10.0 cm) and 50.00% large leaves (>10.0 cm). For leaf width, 37.50% of genotypes recorded narrow leaves (<5.5 cm), 25.00% medium leaves (5.5-7.5 cm) and 37.50% wide leaves (>7.5 cm). Notably, the IGPB-2019 series together with IGPB-2017-01, 02, 04, 05, 06, 07 and 08 consistently combined large leaf length with wide lamina, whereas IGPB-2017-12 to IGPB-2017-17 were consistently small- and narrow-leaved. This combination of large, wide leaves in specific accessions is agronomically important because leaf size is a direct determinant of edible leaf yield in *Basella*.

Leaf apex shape varied as acute (50.00%), obtuse (12.50%) and rounded (37.50%). The acute apex was a characteristic of all reddish-green genotypes, while rounded apices were confined to the green genotypes, and obtuse apices were restricted to IGPB-2017-03, IGPB-2017-04 and IGPB-2017-09. Leaf base shape was rounded in 62.50% of genotypes and cordate in 37.50%; the cordate base was again restricted to the green-leaved group, whereas the reddish-green group was uniformly rounded at the base. Leaf margin type was monomorphic (entire in 100% of genotypes), but leaf margin colour segregated evenly into green (50.00%) and light red (50.00%), matching the leaf-colour grouping. Similarly, leaf midrib pigmentation was absent (green) in 50.00% of genotypes and present (reddish) in 50.00%, with the two states coinciding exactly with the green and reddish-green leaf colour classes.

The consistent co-segregation of leaf colour, leaf margin colour and midrib pigmentation indicates that pigmentation in the leaf lamina, margin and midrib is jointly expressed within each morphotype. Comparable patterns of pigmentation-linked leaf traits have been reported in morphological studies of vine spinach in western Kenya (Oyugi *et al.*, 2022) ^[13] and in green- and red-stemmed forms of *Basella alba* (Bolaji *et al.*, 2023) ^[5], where leaf pigmentation served as a dependable field marker for distinguishing morphotypes. The agronomic relevance of the large-leaved green accessions identified here lies in their potential for high leaf-yield selection, since leaf dimensions are among the primary determinants of marketable yield in leafy vegetables.

Stem and petiole characters

Stem colour, petiole colour and stem pigmentation were among the most discriminating traits. Stem and petiole pigmentation was present in exactly 50.00% of genotypes (IGPB-2017-10 to IGPB-2017-21) and absent in the remaining 50.00%. Petiole colour was green in the unpigmented group and pink in the pigmented group. These pigmentation traits therefore divided the 24 genotypes into two equal classes of twelve, providing a simple and reliable field-level key for grouping the germplasm into *B. alba* (green) and *B. rubra* (reddish-pink) types.

Stem shape was predominantly round (70.83%), with an angular stem recorded in IGPB-2019-01 to IGPB-2019-03, IGPB-2017-02, IGPB-2017-06, IGPB-2017-07 and IGPB-2017-08 (29.17%). Stem surface texture was uniformly smooth across the entire germplasm. Stem thickness ranged

from thin (<0.8 cm, 50.00%) through medium (0.8-1.2 cm, 12.50%) to thick (>1.2 cm, 37.50%). Thin stems were confined to the pigmented (*B. rubra*) group, whereas thick stems were confined to the green (*B. alba*) group. Internode length was short (<1.5 cm) in IGPB-2017-07 and IGPB-2017-18, medium (1.5-2.0 cm) in 83.33% of genotypes and long (>2.0 cm) in IGPB-2017-03 and IGPB-2017-04. Petiole length varied from short (<1.60 cm, 29.17%) and medium (1.60-1.90 cm, 66.67%) to long (>1.90 cm, 4.17%, recorded only in IGPB-2017-03).

The association between stem thickness and morphotype is notable: thick stems in the green group indicate greater structural vigour, whereas thin stems in the pigmented group suggest a comparatively slender vine architecture. A similar correspondence between stem pigmentation, stem diameter and morphotype has been documented in green- versus red-stemmed *Basella alba* forms (Bolaji *et al.*, 2023) [5]. Internode length variation of nearly two-fold between the shortest and longest accessions provides useful scope for selecting erect or spreading vine ideotypes, since compact (short-internode) genotypes are easier to manage under staking.

Growth characters

All 24 genotypes expressed a climbing growth habit; none exhibited prostrate or semi-erect architecture. This uniformity confirms twining/climbing as a fixed, genus-level trait in the present collection rather than a character available for between-genotype discrimination. In agreement with the present findings, climbing or twining growth habit has been reported as the dominant architectural trait in *Basella* germplasm in earlier characterization studies (Oyugi *et al.*, 2022; Sarkar *et al.*, 2021) [13, 15]. Non-climbing or dwarf architecture, if available elsewhere, would constitute a distinct novelty for *Basella* improvement.

Flower characters

Flower colour varied between white (50.00%) and pink (50.00%), with the pink-flowered genotypes corresponding exactly to the pigmented morphotype (IGPB-2017-10 to IGPB-2017-21) and white flowers to the green morphotype. Flower arrangement was clustered in spikes in 100% of genotypes, while solitary flowers were absent. Flower size ranged from small (50.00%) through medium (12.50%) to large (37.50%), following the same distribution as stem thickness. Flowering intensity was low in IGPB-2017-03, IGPB-2017-04, IGPB-2017-07 and IGPB-2017-18 (16.67%), medium in most genotypes (62.50%) and high in IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-09 and IGPB-2017-20 (20.83%) ranged from moderate to profuse, and profuse flowering was generally associated with vigorous growth and higher fruit set.

The complete correspondence between flower colour, leaf colour, stem pigmentation and fruit colour across the two morphotypes indicates that pigmentation genes are expressed pleiotropically in vegetative and reproductive organs of *Basella*. Such morphological integration strengthens the reliability of pigmentation traits as diagnostic markers for species-level classification, consistent with the practical separation of *B. alba* and *B. rubra* practiced in germplasm and varietal identification programmes (Deshmukh and Gaikwad, 2014; Roy *et al.*, 2010) [7, 14].

Fruit and seed characters

Mature fruit colour was the most striking reproductive trait: 50.00% of genotypes produced purple fruits and 50.00% produced dark purple fruits, with no green-fruited genotype in the collection. The dark purple class comprised exclusively the pigmented morphotype (IGPB-2017-10 to IGPB-2017-21), while the purple class comprised the green morphotype (IGPB-2019-01 to IGPB-2019-03 and IGPB-2017-01 to IGPB-2017-09). Fruit shape was uniformly round across all genotypes. Seed colour was uniformly black, indicating limited variability for this trait.

The deep pigmentation of fruits in the *B. rubra* group is of direct industrial interest: betacyanins are the principal pigments responsible for the dark purple fruit colour of *B. rubra*, and fruits of this species have been reported to contain betalain concentrations suitable for natural colourant applications (Kumar *et al.*, 2016) [11]. Genotypes such as IGPB-2017-10 to IGPB-2017-21, which combine dark purple fruits with reddish foliage and pigmented stems, therefore merit priority in screening for betacyanin content and natural food-colour extraction. Conversely, the uniformly black seed colour and uniformly round fruit shape indicate that these traits contribute little to genotype discrimination in *Basella*, and descriptor sets may reasonably assign them low weight in future distinctness, uniformity and stability (DUS) work.

Overall diversity and morphotype classification

Synthesis of the 24 descriptor traits allowed the germplasm to be classified into two well-defined morphotype groups. Group I (*B. alba* type) comprised IGPB-2019-01 to IGPB-2019-03, IGPB-2017-01 to IGPB-2017-09, characterized by green to dark green leaves, unpigmented green stems and petioles, rounded leaf apices, cordate or rounded leaf bases, white flowers, purple fruits and thick stems. Group II (*B. rubra* type) comprised IGPB-2017-10 to IGPB-2017-21, characterized by reddish-green leaves, pigmented pink stems and petioles, acute leaf apices, rounded leaf bases, pink flowers, dark purple fruits and thin stems. Within each group, graded variation in leaf length, leaf width, internode length, petiole length and fruit density provided secondary discrimination among individual genotypes.

The present findings corroborate earlier reports of clear morphotypic differentiation in *Basella* germplasm. Morphological characterization of vine spinach in western Kenya distinguished *B. alba* and *B. rubra* on the basis of stem and leaf colour (Oyugi *et al.*, 2022) [13], and characterization of Indian spinach genotypes under Chhattisgarh plain conditions likewise documented distinctness among accessions for vegetative and reproductive descriptors (Sarkar *et al.*, 2021) [15]. The observation that reproductive pigmentation (flower and fruit colour) mirrors vegetative pigmentation (leaf, stem and petiole colour) is consistent with the single-species-complex hypothesis for *B. alba* and *B. rubra* (Roy *et al.*, 2010) [14], in which a few pigmentation loci control the visually distinct forms, while the remaining characters vary continuously. The descriptor-based approach used here thus proved effective both for morphotype separation and for within-group genotype discrimination, supporting its routine use in germplasm registration and breeding.

Table 1: Morphological Descriptors Used for Phenotypic Characterization of Different *Basella* Genotypes at different growth stages.

Character Group	Descriptor	States of Expression	Score	Genotypes	No. of Genotypes (out of 24)	% age
A. Leaf Characters	Leaf colour (QL)	Light green	1	IGPB-2017-03 and IGPB-2017-04	2	8.33%
		Green	2	-	0	
		Dark green	3	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08 and IGPB-2017-09.	10	41.67%
		Reddish green	4	IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20 and IGPB-2017-21	12	50.00%
	Leaf shape (QL)	Ovate	1	IGPB-2017-03, IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20 and IGPB-2017-21	13	54.17%
		Oval	2	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08 and IGPB-2017-09.	11	45.83%
		Cordate	3	-	0	0
	Leaf length (cm) (QN)	Small (<8.5 cm)	3	IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17	6	25.00%
		Medium (8.5–10.0 cm)	5	IGPB-2017-02, IGPB-2017-03, IGPB-2017-09, IGPB-2017-10, IGPB-2017-11, IGPB-2017-18	6	25.00%
		Large (>10.0 cm)	7	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08, IGPB-2017-19, IGPB-2017-20, IGPB-2017-21	12	50.00%
	Leaf width (cm) (QN)	Narrow (<5.5 cm)	3	IGPB-2017-12, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20, IGPB-2017-21	09	37.50%
		Medium (5.5–7.5 cm)	5	IGPB-2017-03, IGPB-2017-08, IGPB-2017-09, IGPB-2017-10, IGPB-2017-11, IGPB-2017-13	06	25.00%
		Wide (>7.5 cm)	7	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07	09	37.50%
	Leaf apex shape (QL)	Acute	1	IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20, IGPB-2017-21	12	50.00%
		Obtuse	3	IGPB-2017-03, IGPB-2017-04, IGPB-2017-09	03	12.50%
		Rounded	5	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08	09	37.50%
	Leaf base shape (QL)	Rounded	1	IGPB-2017-03, IGPB-2017-04, IGPB-2017-09, IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20, IGPB-2017-21	15	62.50%
		Cordate	3	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08	09	37.50%
		Sagittate	5		0	0.00%
	Leaf margin type (QL)	Entire	1	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-03, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08, IGPB-2017-09, IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20 and IGPB-2017-21	24	100%
		Undulate	2	-	0	0.00%
	Leaf margin colour (QL)	Green	1	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-03, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08 and IGPB-2017-09	12	50.00%
		Light red	2	IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20 and IGPB-2017-21	12	50.00%
		Reddish purple	3	-	0	0.00%
	Leaf midrib pigmentation (QL)	Absent (Green)	1	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-03, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08, IGPB-2017-09	12	50.00%
		Present (Reddish)	9	IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20, IGPB-2017-21	12	50.00%

B. Petiole and Stem Characters	Petiole colour (QL)	Green	1	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-03, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08 and IGPB-2017-09	12	50.00%
		Pink	2	IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20 and IGPB-2017-21	12	50.00%
		Purple	3	-	0	0.00%
	Petiole length (QN)	Short (<1.60 cm)	3	IGPB-2017-07, IGPB-2017-10, IGPB-2017-12, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-21	07	29.17%
		Medium (1.60–1.90 cm)	5	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-08, IGPB-2017-09, IGPB-2017-11, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-19, IGPB-2017-20	16	66.67%
		Long (>1.90 cm)	7	IGPB-2017-03	01	4.17%
	Stem colour (QL)	Absent	1	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-03, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08 and IGPB-2017-09	12	50.00%
		Present	9	IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20 and IGPB-2017-21	12	50.00%
	Stem shape (QL)	Round	1	IGPB-2017-01, IGPB-2017-03, IGPB-2017-04, IGPB-2017-05, IGPB-2017-09, IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20 and IGPB-2017-21	17	70.83%
		Angular	3	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-02, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08,	7	29.17%
	Stem surface texture (QL)	Smooth	1	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-03, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08, IGPB-2017-09, IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20 and IGPB-2017-21	24	100%
		Rough	2	-	0	0.00%
	Stem thickness (QN)	Thin (<0.8 cm)	3	IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20, IGPB-2017-21	12	50.00%
		Medium (0.8–1.2 cm)	5	IGPB-2017-03, IGPB-2017-04, IGPB-2017-09	3	12.50%
		Thick (>1.2 cm)	7	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08	9	37.50%
	Internode length class (QN)	Short (<1.5 cm)	3	IGPB-2017-07, IGPB-2017-18	2	8.33%
		Medium (1.5–2.0 cm)	5	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-05, IGPB-2017-06, IGPB-2017-08, IGPB-2017-09, IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-19, IGPB-2017-20, IGPB-2017-21	20	83.33%
		Long (>2.0 cm)	7	IGPB-2017-03, IGPB-2017-04	2	8.33%
C. Growth Characters	Growth habit (QL)	Prostrate	1	-	0	0.00%
		Semi-erect	3	-	0	0.00%
		Climbing	5	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-03, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08, IGPB-2017-09, IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20, IGPB-2017-21	24	100%
D. Flower Characters	Flower colour (QL)	White	1	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-03, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08 and IGPB-2017-09	12	50.00%
		Pink	3	IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20 and IGPB-2017-21	12	50.00%
		Red	5	-	0	0.00%
	Flower arrangement (QL)	Solitary	1	-	0	0.00%
		Clustered (Spike)	3	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-03, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08, IGPB-2017-09, IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17,	24	100%

				IGPB-2017-18, IGPB-2017-19, IGPB-2017-20, IGPB-2017-21			
	Flower size (QL)	Small	3	IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20, IGPB-2017-21	12	50.00%	
		Medium	5	IGPB-2017-03, IGPB-2017-04, IGPB-2017-09	3	12.50%	
		Large	7	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08	9	37.50%	
	Flowering Intensity (QN)	Low	3	IGPB-2017-03, IGPB-2017-04, IGPB-2017-07, IGPB-2017-18	4	16.67%	
		Medium	5	IGPB-2017-01, IGPB-2017-02, IGPB-2017-05, IGPB-2017-06, IGPB-2017-08, IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-19, IGPB-2017-21	15	62.50%	
		High	7	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-09, IGPB-2017-20	5	20.83%	
	E. Fruit and Seed Characters	Mature fruit colour (QL)	Green	1	-	0	0.00%
			Purple	3	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-03, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08, IGPB-2017-09	12	50.00%
Dark purple			5	IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20, IGPB-2017-21	12	50.00%	
Black			7	-	0	0.00%	
Fruit shape (QL)		Round	1	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-03, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08, IGPB-2017-09, IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20, IGPB-2017-21	24	100%	
		Oval	2	-	0	0.00%	
Seed colour (QL)		Brown	1	-	0	0.00%	
		Black	2	IGPB-2019-01, IGPB-2019-02, IGPB-2019-03, IGPB-2017-01, IGPB-2017-02, IGPB-2017-03, IGPB-2017-04, IGPB-2017-05, IGPB-2017-06, IGPB-2017-07, IGPB-2017-08, IGPB-2017-09, IGPB-2017-10, IGPB-2017-11, IGPB-2017-12, IGPB-2017-13, IGPB-2017-14, IGPB-2017-15, IGPB-2017-16, IGPB-2017-17, IGPB-2017-18, IGPB-2017-19, IGPB-2017-20 and IGPB-2017-21	24	100%	

Note: QL = Qualitative traits (State of expression is based on visual phenotypic categories like shapes, colours, or types) and QN = Quantitative traits (State of expression is based on continuous variation ranges or distinct metric measurements like sizes, lengths, or counts).

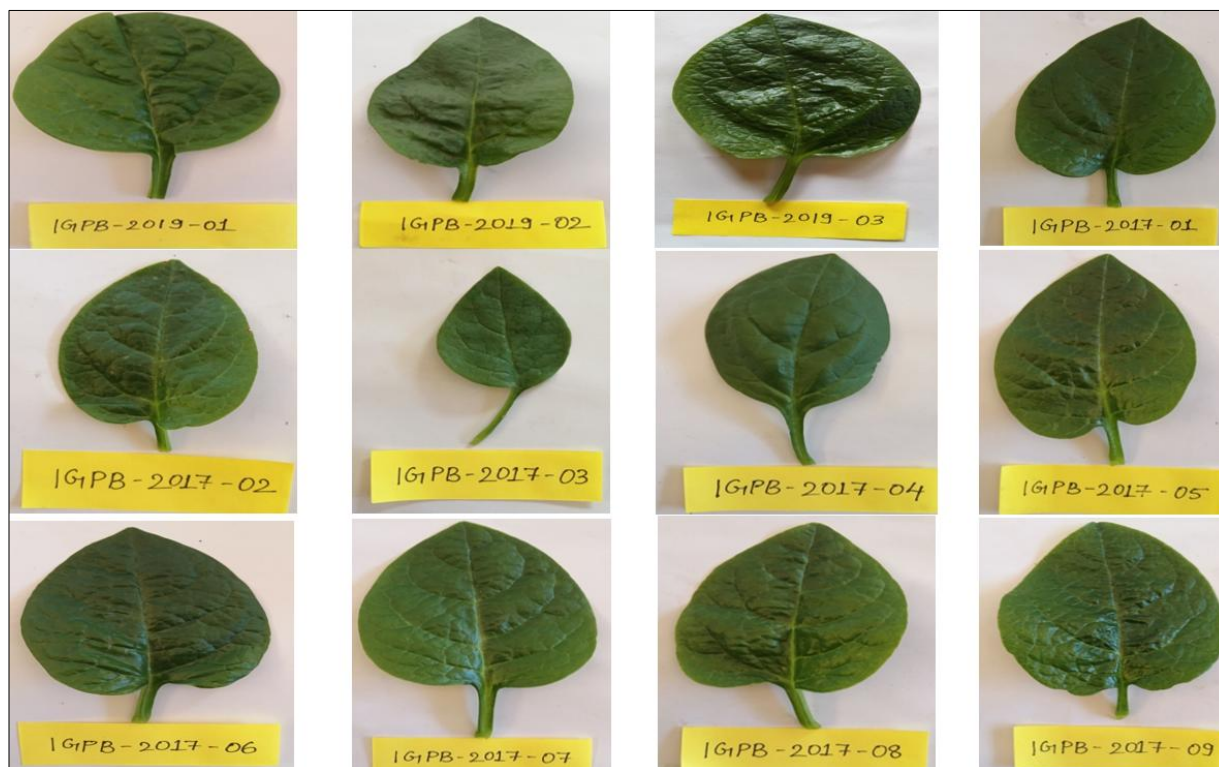


Fig 1 (a): Variation in Leaf and petiole characteristics among different *Basella* genotypes



Fig 1(b): Variation in Leaf and petiole characteristics among different *Basella* genotypes



Fig 2(a): Plant characteristics of different *Basella* genotypes



Fig 2(b): Plant characteristics of different *Basella* genotypes



Fig 3(a): Variation in fruit characteristics among different *Basella* genotypes



Fig 3(b): Variation in fruit characteristics among different *Basella* genotypes

Conclusion

The present study revealed substantial morphological diversity among 24 *Basella* genotypes using standardized descriptor-based evaluation. Clear distinction between *Basella alba* and *Basella rubra* was possible on the basis of leaf pigmentation, stem and petiole colour, midrib pigmentation, flower colour and mature fruit colour, all of which segregated the germplasm into two equal morphotype groups. Leaf length, leaf width, stem thickness, internode length, petiole length, flower size and fruit density provided graded, within-group variation useful for identifying agronomically promising accessions, particularly the large-leaved green genotypes for high leaf yield and the dark-purple-fruited pigmented genotypes for betacyanin-based value addition. Morphological descriptors proved to be effective, economical and field-reliable tools for assessing distinctness and diversity in *Basella*. The variability identified in this study can be utilized for varietal identification, germplasm conservation, DUS testing and future breeding programmes aimed at improving yield, quality and pigment-based value chains in *Basella*.

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Conflict of Interest

The author(s) declare that they have no conflict of interest.

Declaration of Generative AI

The authors declare that AI-assisted tools were used for language refinement and formatting of the manuscript during the preparation of this work. The authors take full responsibility for the content of the manuscript and reviewed and verified the final version.

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