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RESEARCH ARTICLE

Deciphering Morpho-taxonomic Variability in *Lathyrus* Species

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Twenty accessions of *Lathyrus* belonging to four different species such as *L. sativus*, *L. cicera*, *L. aphaca* and *L. odoratus* were obtained from ICAR-National Bureau of Plant Genetic Resources (NBPGR) genebank, New Delhi and the International Center for Agricultural Research in the Dry Areas (ICARDA). All the accessions were grown at the experimental farm of ICAR-NBPGR, New Delhi, India, during the *rabi* seasons of 2018–2019 and 2019–2020. Agro-morphological delineation was carried out using 24 qualitative and 18 quantitative traits by following standard *Lathyrus* descriptors. The results indicated a wide range of variation for both qualitative and quantitative characteristics among the accessions. Remarkable distinguishing feature was observed at the different crop growth stages like seedling, pod and maturity stage. Among the species, *L. odoratus* had early maturity, whereas *L. aphaca* exhibited late maturity. The average value of hundred seed weight was highest in *L. sativus* followed by *L. cicera* and *L. odoratus* while the lowest value was recorded in *L. aphaca*. Based on hierarchical clustering, all accessions were grouped into four clusters. Our findings could be used as reference in species identification and understanding the diversity within and among *Lathyrus* species.

Key Words: *Lathyrus aphaca, L. cicera, L. odoratus, L. sativus,* Morphology, Taxonomy

Introduction

The genus *Lathyrus* is an important, underutilized species, which has the immense potential to be used as human food, animal feed and sustainable agriculture (Campbell, 1997; Tripathi *et al*., 2020) (Fig. 1). It includes about 182 species (POWO, 2019) cultivated around 1.5 m ha throughout the world (Kumar *et al*., 2013; Vaz Patto and Rubiales, 2014). Due to its high biological potential, it can thrive well in various environmental conditions and capacity to improve soil fertility (Polignano *et al*., 2009; Sidorova *et al*., 2013). It is believed that it was originated in two separate regions, *namely*, the Central Asiatic region and the Abyssinian centre of origin (Vavilov, 1951). It is grown in India from 2000 BC (Saraswat, 1980). Sanjappa (1992) mentioned nine species of the genus *Lathyrus* are distributed in India, namely *L. aphaca* L., *L. inconspicuous* L., *L. hirsutus* L., *L. humilis* (Seringe) Fischer ex Spreng., *L. laevigatus* (Waldst. & Kit.), *L. odoratus* L., *L. pratensis* L., *L. sativus* L., *L. sphaericus* Retz. However, Bhellum (2016) reported a new existence of *L. cicera* in the country. Among them, *L. sativus,* commonly known as grasspea is predominantly grown in India, has the great potential to use as grain and forage legume crop in arid areas. It is resilient to several abiotic stresses such as drought, flood and salinity. *L. cicera* is the progenitor of *L. sativus* (Campbell, 1997), which reported as potential donor for cold-tolerance (Robertson *et al*., 1996) and crossable with *L. sativus* (Yunus *et al*., 1991). Apart from this, *L. aphaca* is commonly found as weed and resistant to powdery mildew and thrips (Pandey *et al*., 1996; Pradeep *et al*., 2014). *L. odoratus* was discovered in Sicily in 1695 and has been extensively used as an ornamental plant (Inoue *et al*., 2000; Rice, 2002; Vaz-Patto and Rubiales, 2014).

In the present age of changing climate, there is a need to diversify the cropping system by introducing

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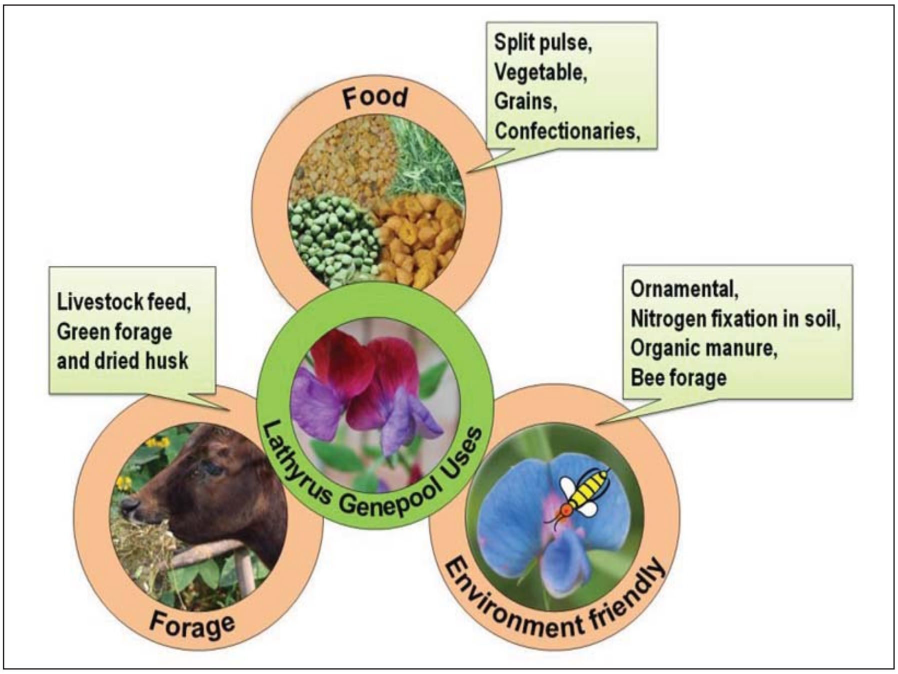

Fig. 1. Manifold use of the *Lathyrus* genepool

the diversity of species, varieties and forms of grain legumes in cropping systems for sustainable agricultural production (Mihailovic *et al*., 2013). The assessment of the genetic diversity and phenotypic characterization of the genetic resources remains the first step for the evaluation, description and categorization of germplasm collections to enhance their proper and rational utilization in crop breeding programs (Bisht *et al*., 2005; Tripathi *et al*., 2018). Principal component analysis (PCA) and clustering are the two main multivariate approaches for genetic diversity estimation. They have been utilized in analyzing the extent of diversity in many *Lathyrus* species (Grela *et al*., 2010). Therefore, the present research was carried out to compare the morphological traits of the selected *Lathyrus* accessions representing four economic species and reveal diversity among accessions by using clustering and PCA approach.

Materials and Methods

Plant Materials

A total of 20 accessions comprising of four species of *Lathyrus viz. L. aphaca*, *L. cicera*, *L. odoratus* and *L. sativus* were obtained from National genebank, ICAR-NBPGR, New Delhi and ICARDA-Food Legume Research Platform, Amlaha, Madhya Pradesh, India. The details of species and accessions, along with passport data, are presented in Table 1.

Table 1. Passport data of experimental materials

Accession	Species	Source of Country
IC572435	*Lathyrus aphaca* L.	India
IC572423	*Lathyrus aphaca* L.	India
IG 64838	*Lathyrus cicera* L.	Syria Arab Republic
IG 64839	*Lathyrus cicera* L.	Syria Arab Republic
EC540952	*Lathyrus cicera* L.	Syria Arab Republic
IC420786	*Lathyrus cicera* L.	India
IG 64857	*Lathyrus cicera* L.	Syria Arab Republic
EC540954	*Lathyrus cicera* L.	Syria Arab Republic
EC720816	*Lathyrus cicera* L.	Syria Arab Republic
EC720817	*Lathyrus cicera* L.	Syria Arab Republic
IC311167	*Lathyrus odoratus* L.	Jharkhand, India
IC319832	*Lathyrus odoratus* L.	India
IC396040	*Lathyrus sativus* L.	India
IC394579	*Lathyrus sativus* L.	India
IC396037	*Lathyrus sativus* L.	India
IC396038	*Lathyrus sativus* L.	India
IC396040	*Lathyrus sativus* L.	India
IC396041	*Lathyrus sativus* L.	India
IC396042	*Lathyrus sativus* L.	India
IC444256	*Lathyrus sativus* L.	India

Experimentation, Data Collection and Statistical Analysis

All accessions were grown at ICAR-NBPGR, New Delhi, India (28.08 °N, 77.12 °E and the height above mean sea level 228.61 meters) during the winter (*Rabi*) season of 2018–2019 and 2019–2020 for agro-morphological characterization and evaluation.

Seeds of each accession were sown in pots in five replications. Due to the staggered germination factors, to avoid the hardiness of seed coat, scarification was done to facilitate proper water imbibitions for promoting good germination in all accessions (Gore *et al*., 2019, Singh *et al*., 2020). Standard agronomic practices were followed as and when necessary to obtain healthy crop growth. All these annual *Lathyrus* species were characterized for 24 qualitative and 18 quantitative traits using standard *Lathyrus* descriptors published by Bioversity International (Table 2). During observations, the plant parts were observed with the help of the naked eye, hand lens (10x), and some typical vegetative characters like stipules and all the floral characters noted using stereo-microscope (Lmi, SZM 12) with dissected floral parts. Ten random samples were taken from each accession of the particular species to record the data on quantitative characters. The data were subjected to statistical analysis using MS Office Excel and SPSS software.

Results

Distinctive morphological characters of the *L. sativus, L. cicera, L. aphaca* and *L. odoratus* were recorded at the vegetative, flowering, podding and post-harvest stages.

Vegetative Characteristics

Semi-erect type of plant growth habit was recorded in *L. sativus* and *L. cicera*, whereas spreading type was found in *L. aphaca* and *L. odoratus.* The three species *L. sativus*, *L. cicera* and *L. odoratus* had one pair of leaflets while *L. aphaca* had reduced into simple tendril leaflets. The shape of the leaflet was linear in *L. sativus* and *L. cicera,* whereas ovate in *L. odoratus.* Stipules were prominent and persistent in all four species. The shape of stipules was semi-sagittate in *L. sativus;* semi-hastate in *L. cicera* and *L. odoratus,* while fallacious ovate-hastate in *L. aphaca.* Stem sections were square in *L. sativus*, *L. cicera* and *L. aphaca* while cylindrical in *L. odoratus.* The waxiness on the stem was observed in all studied species (Fig. 2).

Flower Characteristics

Blue coloured flower was recorded in *L. sativus*. Red coloured flower was recorded in *L. cicera,* creamish white to light yellow in *L. aphaca*; while in *L. odoratus* standard petal were bright pink colour and purple colour wing petals. All species possess single flower per peduncle except *L. odoratus* where 2-3 flowers were observed. The smallest flower size was recorded in *L. aphaca*; medium in *L. sativus and L. aphaca,* while flower was largest in *L. odoratus* (Fig. 3).

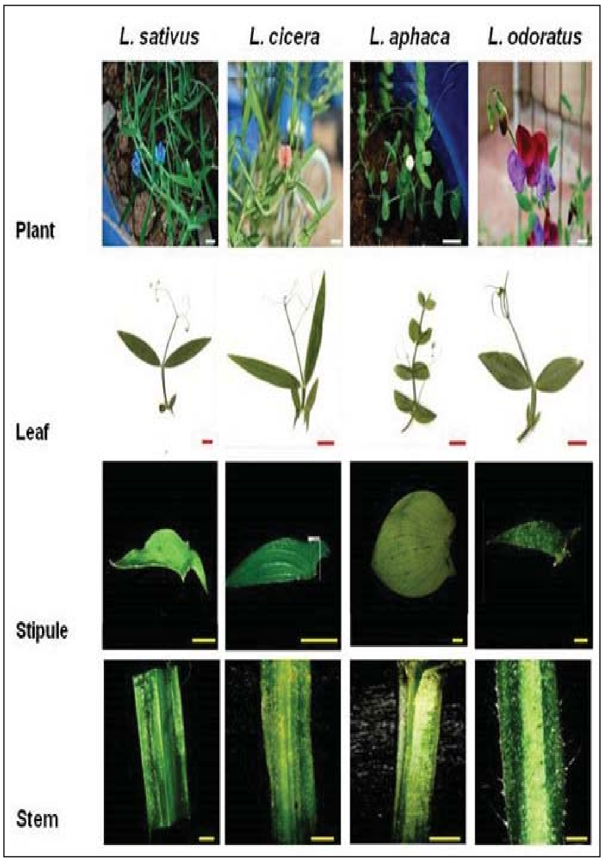

Fig. 2. Vegetative characteristics of *L. sativus*, *L. cicera*, *L. aphaca* and *L. odoratus* (bar scale: white colour bar = 10 cm, red colour bar = 1 cm, yellow colour bar = 0.1 cm)

Pod Characteristics

The morphology of pod was one of the essential characters in distinguishing all four species. Pod shape was medium oblong elliptical in *L. sativus* and *L. cicera*; beaded in *L. aphaca* while broad linear in *L. odoratus.* The colour of the mature pod was yellowish-brown in *L. sativus* and *L. cicera;* brown in *L. aphaca* and creamy yellow *L. odoratus.* Pod beak shape was pointed in *L. sativus, L. cicera* and *L. aphaca* whereas, blunt in *L. odoratus*. Wings on the pod were narrow observed in *L. sativus* while other species (*L. odoratus*, *L. aphaca* and *L. cicera*) were wingless. All species had glabrous pod except *L. odoratus* where it was pubescent (Fig. 3). Shattering of pods at maturity was observed only in *L. aphaca.*

Table 2. Descriptor traits used in study of *Lathyrus* species

Qualitative	Descriptor State
Early plant vigour	Poor (1), Good (2), Very good (3)
Plant Growth Habit	Prostate (1), Spreading (2), Semi-erect (3), Erect (4)
Plant type	Indeterminate (1) Determinate (2)
Nodes per plant	Few (3), Medium (5), Many (7)
Stem colour	Light green (1), Green (2), Purple-green (3), Purple (4), Other (99)
Stem wing width	Wingless (0), Small (3), Medium (5), Large (7)
Stem waxy coating	No coating (0), Small (3), Medium (5), Large (7)
Stem section shape	Round (1) Square (2) Deeply fasciated (3), Other (99)
Root nodulation	No nodules (0), Low (3), Intermediate (5), High (7)
Branch arrangement	Evenly distributed throughout the whole plant (1), Mainly on lower part of the plant (2) Mainly in middle part of the plant (3)
Anthocyanin pigment colour	Absent (0), Present (1)
Leaf type	Tendril (1), Phyllody (2), Simple (3), Bipinnate (4), Multipinnate (5), Other (99)
No of leaflets per leaf	One pair (1), Two pairs (2), More than two pairs (3)
Leaf colour	Light green (1), Green (2), Dark green (3), Other (99)
Prominence of leaf vein	No (0), Yes (1)
Pigmentation of leaf vein	No (0), Yes (1)
leaf size	Small (3), Medium (5), Large (7)
Leaflet shape	Linear (1), Lanceolate (2), Ovate (3)
Leaf petiole colour	Green (1), Purple-green (2) Other (99)
Leaf tendrils	Absent (0), Short (1), Medium (2), Long (3), Other (99)
Top leaves petiole end	Tendril subulate (1) Tendril simple (2), Tendril compound (3), Other (99)
Lower leaves petiole end	Tendril subulate (1), Tendril simple (2), Tendril compound (3), Other (99)
Leaf persistance	Low (3), Moderate (5), High (7)
Leaf senescence	No visual senescence (0), Slight visual senescence (3), Moderate senescence (5), Conspicuous concurrent senescence (7)
Leaf pubescence	Absent (0), Present (1)
Stipule shape	Sagittate (1), Semi-sagitatte (2)
Flower colour	White (1), White blue (2), Blue (3), Grey (4), Light Yellow (5), Yellow (6), Pink (7), Orange (8), Red (9), Violet-blue (10), Violet (11), Other (99)
Flower size	Small (3), Medium (5), Large (7)
Pod colour immature	Yellow-cream (1), Light green (2), Green (3), Dark green (4), Green-purple (5), Light purple (6), Purple (7), Other (99)
Pod colour mature	Yellow-green (1), Violet mottled (2), Grey (3), Other (99)
Pod pigmentation	Uniformly green (1), Uniformly pigmented (2), Mottled (3), Other (99)
Pod shape	Oblong-elliptical (1), Medium oblong-elliptical (2), Curved (3), Beaded (4), Broad-linear (5), Broad-elliptical (6), Other (99)
Pod curvature	Straight (1), Slightly curved (2), Curved (3)
Pod beak shape	Pointed (1), Blunt (2), Other (99)
Pod pubescence	Absent (0), Low (3), Medium (5), High (7)
Pod dehiscence	No shattering (0), Low shattering (3), Medium shattering (5), High shattering (7)
Pod wings	Absent (0), Narrow (3), Medium (5), Wide (7)
Seed shape	Oblate or flattened (1), Triangular (2), Rhomboid (3), Square (4), Obtriangular (5), Spherical (6), Other (99)
Seed coat colour	Greyed-white (1), Yellow-white (2), Grey (3), Brown (4), Yellow-green (5), Pink (6), Red-purple (7), Black (8), Grey mottled (9), Green mottled (10), Other (99)
Seed coat surface	Smooth (1), Tubercular (2)
Seed coat pattern	Absent (0), Marbled (1), Dotted (2), Streaked (3), Mixture (4)
Seed coat pattern colour	Cream (1), Green (2), Brown (3), Red-purple (4), Black (5), Other (99)
Seed size	Small (3), Medium (5), Large (7)
Cotyledon colour	Yellow (1), Orange (2), Other (99)
Seed ornamentation	Absent (0), Present (1)

Table 3. Distinctive characteristics of four species of *Lathyrus*

Traits	*L. sativus*	*L. cicera*	*L. aphaca*	*L. odoratus*
Vegetative characteristics				
Plant growth habit	Semi-Erect	Semi-Erect	Spreading	Spreading
Leaflet shape	Linear	Linear	Tendril	Ovate
Number of leaflets	One pair	One pair	Reduced to a simple tendril	One pair
Stipule shape	Semi-saggitate	Semi-hastate	Fallacious ovate-hastate	Semi-hastate
Stem wing	Present	Narrow	Absent	Present
Stem section	Square	Square	Cylindrical	Square
Floral characteristics				
Number of flowers per inflorescence	1	1	1	2-3
Flower colour	Blue	Brick Red	Light Yellow	Pink
Flower size	Medium	Medium	Small	Large
Pod and seed characteristics				
Pod shape	Medium oblong elliptical	Medium oblong elliptical	Beaded	Broad linear
Mature pod colour	Yellowish Brown	Yellowish Brown	Brown	Yellowish
Immature pod colour	Light Green	Light Green	Dark Green	Light Green
Pod beak shape	Pointed	Pointed	Pointed	Blunt
Pod wings	Narrow	Absent	Absent	Absent
Pod pubescence	Absent	Absent	Absent	High
Pod dehiscence	No shattering	No shattering	Medium shattering	No shattering
Seed shape	Rhomboid-Obtriangular	Rhomboid-Obtriangular	Spherical	Spherical
Seed coat colour	Grey Mottled	Brown Mottled	Grey Mottled	Blackish Grey
Seed size	Large	Medium	Small	Medium
Seed coat surface	Tubercular	Tubercular	Smooth	Smooth
Seed coat pattern	Marbled	Absent	Marbled	Dotted
Seed eye width	Narrow	Narrow	Narrow	Wide
Shattering	Absent	Absent	Present	Absent

Seed Characteristics

The morphology of seed characters was studied with the naked eye and under the stereo-microscope are presented in Table 3 and Figure 3. The four species can be identified easily at the seed stage prominently by observing the seed's size, colour, and shape. Seeds of *L. sativus* and *L. cicera* were rhomboidal obtriangular in shape with tuberculate surface. The seed shape was spherical, with smooth surface observed in *L. aphaca* and *L. odoratus.* Seed coat colour was observed grey mottled in *L. sativus* and *L. aphaca* whereas brown mottled in *L. cicera* and blackish-grey in *L. odoratus.* Among all studied species, the smallest seed was observed in the *L. aphaca*; medium in *L. cicera* and *L. odoratus* while the largest in *L. sativus*.

Quantitative Traits

Wide variation for quantitative traits was recorded in *L. sativus, L. cicera, L. odoratus* and *L. aphaca* (Table 4). The mean value of plant height was 91.70 and 91.21 cm in *L. sativus* and *L. cicera*, respectively. The tallest plant was recorded (113 cm average plant height) in *L. odoratus*, whereas two times shorter plant height was recorded (an average of 51.63 cm) in *L. aphaca*. Length of internode was also similar in case of *L. sativus* (5.35 cm) and *L. cicera* (5.52 cm), whereas, *L. odoratus* had comparatively shorter internode length (4.00 cm) followed by *L. aphaca* (2.50 cm). Petiole and pedicle length were short in *L. aphaca* whereas, the longest in *L. odoratus* followed by *L. sativus* and *L. cicera.* In the present study, an average number of primary branches 3.50, 3.62, 5.00 and 5.54 were recorded on *L. aphaca, L. sativus, L. odoratus and L. cicera*, respectively. The mean number of days to flowering of *L. sativus* and *L. cicera* was recorded 70 and 75 days, respectively. The *L. aphaca* accessions was flowered in 89 days, while the lowest was recorded in *L. odoratus* (60 days). The average number of pods in *L. sativus* accessions amounted to 37.62, while it was lesser in *L. aphaca* (27.33) and *L. odoratus* (25.17) than *L. sativus*. Highest number of pods per plant was recorded in *L. cicera* (45.62). The pod was longer in *L. odoratus* (5.52 × 1.10 cm) while the medium in *L. sativus* (2.96 × 0.82 cm) and *L. cicera* (2.75 × 0.76 cm) and smallest in *L. aphaca*

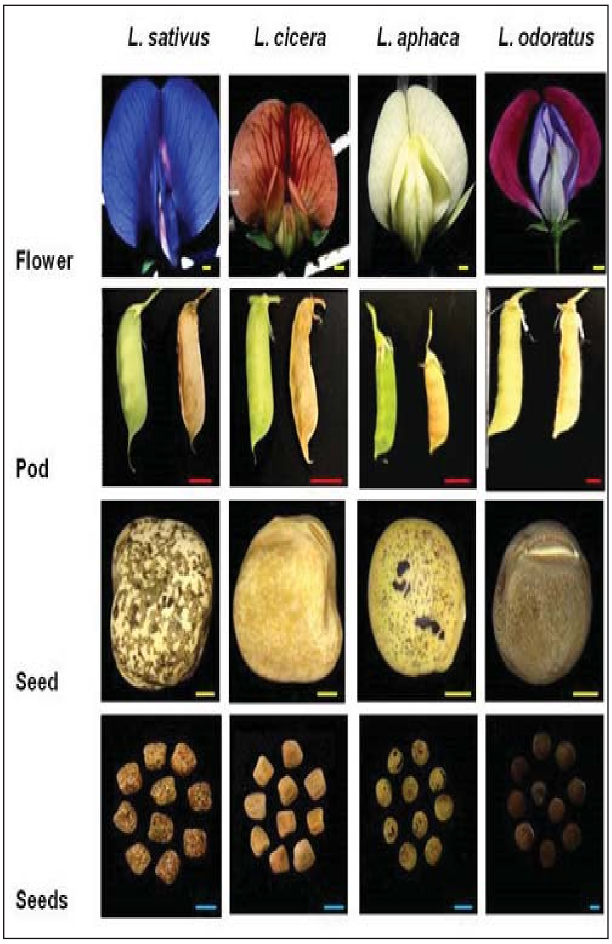

Fig. 3. Floral and pod characteristics of *L. sativus, L. cicera, L. aphaca* and *L. odoratus* (bar scale: white colour bar = 10 cm, red color bar = 1 cm, yellow colour bar = 0.1 cm, blue colour bar = 0.5 cm)

(2.05 × 0.587). The average number of seeds per pod was the highest in *L. odoratus* followed by *L. aphaca, L. sativus* and *L. cicera.* Wide variation was observed for 100-seed weight among the *Lathyrus* species. The mean highest value for 100-seed weight was recorded in *L. sativus* (8.83 g) followed by *L. cicera* (6.99 g) and *L. odoratus* (5.11 g), whereas *L. aphaca* (1.30 g) showed the lowest 100-seeds weight. Seed diameter was correlated with 100-seed weight as it was the highest in *L. sativus* (0.47 cm) followed by *L. cicera* (0.41cm) and *L. odoratus* (0.34 cm) whereas lowest in *L. aphaca* (0.26 cm).

Inter-relationship Studies among Quantitative Traits

Correlation analysis revealed that plant height strongly correlated with leaflet, standard petal, pod size, petiole and pedicle length, and 100-seeds weight. In contrast, a strong negative correlation was observed with the number of days to flowering and maturity. Hundred seed weight positively correlated with pod length, leaflet length and seed diameter (Table 5). The number of seeds per pod had a positive relation with petiole and pedicle length and pod length while negative with seed diameter. Pod length and plant height were negatively correlated with days to flowering and maturity.

Hierarchical Clustering and Principal Component Analysis

Based on hierarchical clustering dependent upon Euclidian distance using the Wards method, all accessions were grouped into four clusters. Cluster-I contained accessions of *L. aphaca*, and cluster-II had *L. odoratus,* while III and IV clusters contain *L. sativus* and *L. cicera* both (Figure 4). The interrelationships among the different parameters were studied through PCA based on correlations. The first three principal components summarized a realistic summary of all data explaining 87.16% variance in *Lathyrus* germplasm considered in

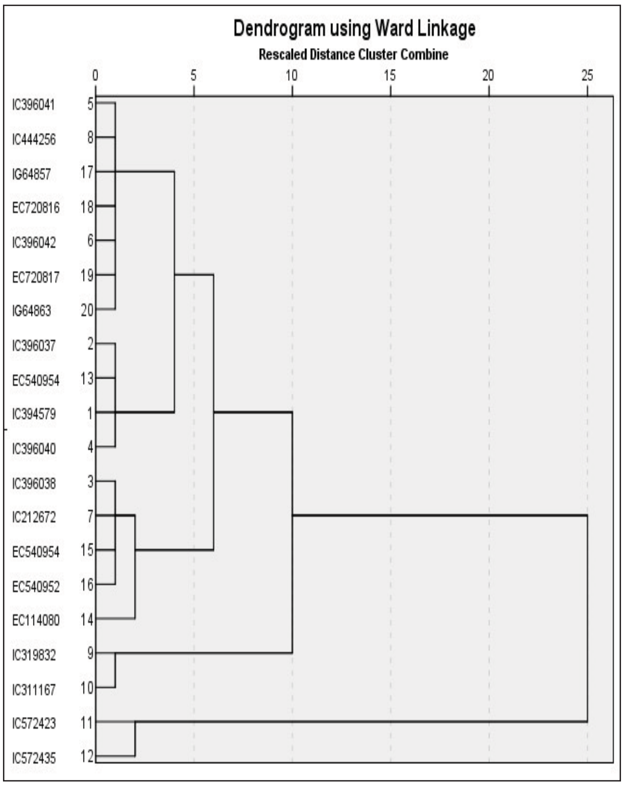

Fig. 4. Dendrogram by Ward's method based on Euclidian distance revealing genetic diversity and relationship among 20 accessions of *Lathyrus* as indicated by quantitative traits

Table 4. Mean value of quantitative characters

Trait	*L. sativus*	*L. cicera*	*L. aphaca*	*L. odoratus*
Plant height (cm)	91.70* ± 1.95**	91.21 ± 2.09	52.63 ± 4.20	113.00 ± 2.5
Internode length (cm)	5.35 ± 0.43	5.52 ± 0.19	2.50 ± 0.50	4.00 ± 0.215
Petiole length (cm)	1.56 ± 0.19	1.25 ± 0.06	0.50 ± 0.08	2.65 ± 0.11
Pedicel length (cm)	3.45 ± 0.32	3.12 ± 0.05	2.43 ± 0.10	5.27 ± 0.13
Leaflet length (cm)	5.9 ± 0.24	5.45 ± 0.13	2.28 ± 0.12	5.55 ± 0.28
Leaflet width (cm)	0.62 ± 0.05	0.58 ± 0.05	0.37 ± 0.03	2.68 ± 0.38
Number of primary branches	3.62 ± 0.35	5.54 ± 0.36	3.50 ± 0.50	5.00 ±1
Nodes to the first bearing pod	8.66 ± 0.17	8.20 ± 0.22	7.17 ± 0.17	5.00 ±0.5
Number of days to first flowering	70.91 ± 1.03	75.66 ± 2.29	89.33 ± 2.83	60.00 ± 2
Standard petal length (cm)	2.04 ± 0.02	2.75 ± 0.02	1.42 ± 0.05	3.20 ± 0.17
Standard petal width (cm)	2.20 ± 0.02	2.36 ± 0.03	1.47 ± 0.10	3.08 ± 0.01
Number of days to 80% maturity	101.45 ± 0.89	101.25 ± 2.78	121.17 ± 0.50	95.17 ± 0.16
Number of pods per plant	37.62 ± 2.76	45.62 ± 2.70	27.33 ± 3.17	25.17 ± 1.16
Pod length (cm)	2.96 ± 0.16	2.75 ± 0.07	2.05 ± 0.25	5.52 ± 0.28
Pod width (cm)	0.82 ± 0.09	0.76 ± 0.03	0.57 ± 0.04	1.10 ±0.095
Number of seed per pod	3.97 ± 0.16	3.91 ± 0.12	4.00 ± 0.33	5.00 ±1
100 seed weight (g)	8.83 ± 0.38	6.99 ± 0.27	1.30 ± 0.02	5.11 ± 0.04
Seed diameter (cm)	0.47 ± 0.01	0.41 ± 0.01	0.26 ± 0.03	0.34 ± 0.03

*: Average value; **: Standard Errors (SE)

Table 5. Correlation matrix of quantitative traits

Traits	PH	IL	NFPB	DF	DM	NPB	LL	LW	PL	PDL	SPL	SPW	NPP	PoL	PoW	NSP	HSW	SD
PH																		
IL	0.595**																	
NFPB	-0.007	0.301																
DF	-0.738**	-0.133	0.037															
DM	-0.850**	-0.427	-0.129	0.814**														
NPB	0.332	0.018	-0.324	0.016	-0.304													
LL	0.841**	0.828**	0.224	-0.526*	-0.713**	0.131												
LW	0.515*	-0.059	-0.714**	-0.525*	-0.342	0.321	0.211											
PL	0.759**	0.417	-0.363	-0.665**	-0.582**	0.053	0.609**	0.768**										
PDL	0.647**	0.227	-0.508*	-0.495*	-0.450*	0.25	0.445*	0.720**	0.831**									
SPL	0.723**	0.328	-0.376	-0.433	-0.590**	.666**	0.432	0.640**	0.532*	0.505*								
SPW	0.831**	0.326	-0.407	-0.628**	-0.661**	.490*	0.561*	0.789**	0.738**	0.679**	0.896**							
NPP	0.258	0.607**	0.460*	0.278	-0.124	0.323	0.369	-0.373	-0.086	-0.062	0.191	0.058						
PoL	0.653**	0.116	-0.658**	-0.667**	-0.540*	0.258	0.389	0.885**	0.881**	0.840**	0.617**	0.802**	-0.289					
PoW	0.540*	0.398	-0.510*	-0.294	-0.391	0.318	0.538*	0.664**	0.736**	0.782**	0.421	0.599**	0.043	0.714**				
NSP	0.33	-0.225	-.618**	-0.342	-0.219	0.409	0.042	0.812**	0.477*	0.661**	0.486*	0.581**	-0.377	0.665**	0.556*			
HSW	0.653**	0.530*	0.308	-0.595**	-0.541*	-0.247	0.784**	0.192	0.577**	0.351	0.031	0.347	0.089	0.358	0.383	0.04		
SD	0.466*	0.685**	0.603**	-0.274	-0.394	-0.236	0.766**	-0.291	0.134	0.012	-0.013	0.126	0.358	-0.135	0.054	-0.351	0.700**	

(PH: plant height; IL: internode length; NFPB: nodes to the first bearing pod: DF: days to flowering; DM: days to maturity; NPB: number of primary branches; LL: leaflet length; LW: leaflet width; PL: petiole length; PDL: pedicel length; SPL: standard petal length; SPW: standard petal width; NPP: number of pods per plant; PoL: pod length; PoW: pod width; NSP: number of seeds per pod; HSW: 100 seed weight; SD: seed diameter)

this study. The first Principal Component (PC1) was the most important, accounting for 47.12% of the total variation. PC1 was loaded on plant height, petiole and pedicel length, leaflet length and width, pod length and width and the number of seeds per pod. PC2 accounted for 23.92 % variance, and it was loaded on internode length, nodes to the first bearing pod, 100-seed weight and seed diameter. PC3 contributed 10.91% variance mainly through a number of primary branches, number of days to first flowering and number of pods per plant (Table 6).

Discussion

The phenetic or taximetrics concept attempts to classify organisms based on morphology or other observable traits of the species delineation for their evolutionary or phylogeny relation (Schneider *et al*., 2016; Gore *et al*., 2019; Ivana *et al*., 2020). The present study highlighted

Table 6. Principal component (PC) matrix explaining loading of variables.

Trait	Component		
	1	2	3
Plant height	0.90	0.35	0.09
Internode length	0.43	0.73	0.23
Petiole length	0.90	-0.01	-0.24
Pedicel length	0.83	-0.21	-0.07
Leaflet length	0.71	0.66	0.02
Leaflet width	0.79	-0.53	-0.10
No of primary branches	0.37	-0.25	0.79
Nodes to the first bearing pod	-0.37	0.82	-0.05
No of days to first flowering	-0.73	-0.13	0.43
stranded petal length	0.75	-0.13	0.50
stranded petal width	0.91	-0.09	0.20
No of days to 80% Maturity	-0.75	-0.35	-0.01
No of pods/plant	0.00	0.59	0.69
Pod length	0.89	-0.35	-0.17
Pod width	0.77	-0.12	0.05
No of seed per pod	0.60	-0.61	-0.02
100 seed weight	0.55	0.59	-0.45
Seed diameter	0.21	0.88	-0.14
Total	8.48	4.31	1.96
% of Variance	47.12	23.92	10.91
Cumulative %	47.12	71.04	81.96

the characterization of the morphological traits for delineating and revealing the diversity pattern.

During morphological characterization of different accessions of the selected species, it was observed that *L. sativus, L. cicera* and *L. odoratus* had one pair of leaflets and it is reduced into simple tendril leaflets in *L. aphaca*. Hofer *et al*. (2009) suggested selective advantage of the tendril enable plants to reach the canopy, increase the opportunity for pollination, photosynthesis and seed dispersal with minimal energy investment. Whereas, Gianoli (2004) emphasized that the climbing habit (tendril) is associated with species/cultivars richness compared with non-climbing habit sister taxa. The waxy coating on the stem was observed in all studied species. Mitra *et al.* (2020) suggested that the amount and composition of the waxy coating and their chemical compounds (alkanes, esters, aldehydes, fatty acids, and alcohols) may vary widely within species. *L. sativus* had blue coloured flowers. IPGRI (2000) also reported that in *L. sativus,* the blue-flowered type is common in South Asia, while the white-flowered type is commonly found in the Mediterranean region. Shattering of pods at maturity is one of the prominent traits of wild species. In the present study, shattering was observed only in *L. aphaca*. Ogutcen *et al.* (2018) reported that indehiscence is a preferred trait in cultivated crops, especially in legumes by breeders, because shattering makes harvesting difficult and lead to significant yield loss. In *L. sativus* and *L. cicera,* seed shape was rhomboidal obtriangular with tuberculate surface. Similarly, Singh and Roy (2013) and Barpete (2015) demonstrated a highly predominating rhomboid seed shape in *L. sativus.* Based on morphological traits, all four studied species can be differentiated. Similar studies were carried out in genus *Vigna* (Gore *et al.* 2019), suggested that morphological characteristics can be used to delineate closely related species.

Several researchers have carried out the morphological characterization of Lathyrus species (Tay *et al*., 2000; Benkova and Zakova, 2001; Dela Rosa and Martın, 2001; Kumari, 2001; Tavoletti *et al*., 2005; Grela *et al*., 2012). All the previous studies suggested a wide range of exploitable variations in *Lathyrus* species. In the present study, wide variation for quantitative traits was recorded. Similar plant height was recorded for *L. sativus* and *L. cicera*. Earlier studies on *L. sativus* and *L. cicera* suggested that plant height varies in different environmental conditions (Campbell, 1997; IPGRI, 2000; Grela *et al.,* 2010). The number of branches per plant is an essential character that has a substantial impact on plant productivity (Basaran *et al*., 2013). In the present study, *L. odoratus and L. cicera* were recorded with more number of primary branches as compared to the *L. aphaca* and *L. sativus,* and similar observations were made by Kosev and Vasileva (2019). The flowering is a complex phenomenon (from vegetative to reproductive stage), and it varies among species as well as genotypes in legumes (Putterill *et al*., 2013; Barpete *et al.,* 2020). In the present study, *L. aphaca* was late maturing, and *L. odoratus* had early maturity among all the species studied. The highest number of pods per plant was recorded in *L. cicera*. Wide variation was observed for 100-seed weight among the *Lathyrus* species. The highest value for 100-seed weight was recorded in *L. sativus* while the lowest in *L. aphaca*. Rybinski *et al.* (2008) reported wide variation for 100-seeds weight in *L. sativus.* The grain productivity in *L. sativus* was dependent mainly number of pods per plant and seeds per pod (Donskoy, 2013). Seed diameter was correlated with

100-seed weight as it was highest in *L. sativus*. Larger seeds are always preferred for selections by a breeder (Chowdhury and Slinkard, 2000). Because, large seed size may increase seed yield that desired for any crop improvement programmes, including *Lathyrus* gene pool (Campbell, 1997). Polignano *et al.* (2005) emphasized that *L. sativus* has tremendous potential for cultivation, mainly for grain purposes. Similar studies reported high variability in morphological and agronomical traits in field evaluation of *Lathyrus* species, indicated high breeding potential in *Lathyrus* gene pool (Tay *et al*., 2000; De la Rosa and Martın, 2001; Kumari, 2001; Benkova and Zakova, 2001; Tadesse and Bekele, 2003; Tavoletti *et al*., 2005; Grela *et al*., 2012).

Correlation analysis revealed that plant height strongly correlated with leaflet, standard petal, pod size, petiole and pedicle length, and 100-seeds weight. Hanbury *et al*. (1995) reported that increased seed size is positively correlated with higher seed yield. Therefore, plant breeders considered increasing seeds per pods in large-seeded cultivars as an effective means of increasing yield. In the present study, the number of seeds per pod positively related to petiole and pedicle length and pod length while negative with seed diameter. Pod length and plant height were negatively correlated with days to flowering and maturity. These results were in consonance with previous studies (Jackson *et al*., 1984; Hanbury *et al*., 1999; Nakamura *et al*., 2010; Kosev and Vasileva, 2019) on studies of different *Lathyrus* species.

Possibility to distinguish a large number of accessions into small homogenous clusters make it easier to select diverse parents for future breeding programme. It does not only facilitates a comparison among the feasible pairs of individuals but also helps in bringing together all possible combinations of gene constellations, thereby making it possible to construct desirable progenies with multiple traits through hybridization. Based on hierarchical clustering dependent upon Euclidian distance using the Wards method, all accessions were grouped into four clusters. Cluster-I contained accessions of *L. aphaca,* and cluster-II had *L. odoratus,* while III and IV clusters contain *L. sativus* and *L. cicera* both. The interrelationships among the different parameters were studied through PCA based on correlations. DelaRosa and Martin (2001) reported similar results of variability distribution from a study with 150 accessions of *L. sativus.*

The present study demonstrated substantial morphological variation in studied *Lathyrus* species. These species were characterized for morpho-taxonomical descriptor traits. Based on descriptor traits, results indicated the similarity in characteristics of *L. cicera* and *L. sativus*. The *Lathyrus* species showed a substantial variation for days to flowering and maturity. A positive correlation between pod size and 100-seed weight was found in the study. This study of *Lathyrus* provide insights on exploiting wild germplasm and information on floral traits for the readily crossable wild species with cultivated genepool. In India, characterization of available *Lathyrus* genepool and collection of new germplasm from untapped areas should be prioritized to enhance the utilization of this minor multi-purpose legume.

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