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Morphological characterisation and assessment of phenotypic diversity of *Abelmoschus sagittifolius* (Kurz) Merr. germplasm in Vietnam

Abstract

The collection, conservation, and characterization of plant germplasm resources are fundamental steps for breeding programmes and the development of high-yielding and high-quality cultivation systems. In the present study, twenty accessions of *Abelmoschus sagittifolius* (Kurz) Merr., representing cultivated populations from ten provinces/cites (nine administrative units after consolidation) across six ecological regions of Vietnam, were evaluated based on phenotypic traits in order to assess morphological variation and phenetic relationships among accessions. A total of 26 phenotypic characters related to growth habit, stem, leaf, floral, fruit, and seed morphology were recorded using standardized morphological descriptors. Phenetic relationships were analysed using similarity coefficients and cluster analysis based on the UPGMA method. The accessions were classified into four major phenetic groups at an average similarity coefficient of 0.38, with similarity values ranging from 0.12 to 0.73. Significant variation was observed among accessions in both vegetative and reproductive traits, particularly plant growth habit, leaf morphology, floral colour variation, and tuber-related characteristics. Notably, BC12 and BC13 from Phu Yen showed the highest tuber fresh weight, reaching 201.30 ± 2.46 and 199.00 ± 2.01 g/plant, respectively, while BC13 also exhibited the greatest morphological divergence, particularly in flower morphology and growth habit. No clear relationship was observed between phenetic grouping and ecological distribution, suggesting that phenotypic variation may reflect both environmental adaptation and genetic differentiation. The results provide important baseline information for germplasm conservation, taxonomic studies, and the future selection and breeding of high-yielding *A. sagittifolius* cultivars in Vietnam.

Key words: Bo Chinh ginseng, morphological features, phenotypic analysis, Pink Swamp Mallow, UPGMA method
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Introduction

Medicinal plants represent an essential source of bioactive compounds with applications in the pharmaceutical, nutraceutical, and functional food industries. In recent years, increasing attention has been directed towards plant-derived compounds because of their antioxidant, anti-inflammatory, antidiabetic, and anticancer properties (Nguyen et al., 2026). These bioactivities are primarily associated with secondary metabolites such as phenolics, flavonoids, alkaloids, and terpenoids, which are known to play important roles in disease prevention and health promotion.

The genus *Abelmoschus* Medikus (Malvaceae Juss.) comprises several economically and medicinally important species distributed throughout tropical and subtropical regions. Members of this genus are widely used in agriculture, food production, and traditional medicine, and exhibit considerable morphological variability and taxonomic complexity due to hybridisation and environmental adaptation (Li et al., 2020). Among them, *Abelmoschus sagittifolius* (Kurz) Merr., commonly known in Vietnam as Bo Chinh ginseng, Tho Hao ginseng, or Phu Yen ginseng, is a valuable medicinal plant widely used in traditional medicine (Do et al., 2006). *A. sagittifolius* is a perennial medicinal herb characterised by slender pubescent stems, tuberous roots, palmately lobed or lanceolate leaves, and solitary axillary flowers exhibiting considerable colour variation. The species is naturally distributed across Southeast Asia, southern China, India, and northern Australia (Do et al., 2006; Tang et al., 2007; Do, 2016). In traditional medicine, the tuberous roots constitute the primary medicinal part and are widely used as a tonic, restorative agent, and nutritional supplement (Do, 2016).

In earlier taxonomic treatments, Bo Chinh ginseng was recorded under the name *Hibiscus sagittifolius* Kurz var. *quinquelobus* Gagnep. and distinguished from Bao ginseng, identified as *Hibiscus sagittifolius* Kurz var. *septentrionalis* Gagnep. (Do et al., 2006). However, most published studies have not clearly differentiated between these taxa and generally recognise them as a single species, *A. sagittifolius* (Do, 2016). According to the Vietnamese Pharmacopoeia V, the currently accepted scientific name is *Abelmoschus sagittifolius* (Kurz) Merr. (*Ministry of*

Health, 2019), although the species is associated with numerous synonyms worldwide (*POWO*, 2021), reflecting its considerable taxonomic complexity.

Phytochemical investigations have demonstrated that *A. sagittifolius* contains a wide range of bioactive compounds, including phenolics, flavonoids, terpenoids, and sterols, which contribute to its pharmacological activities, such as antioxidant, cytotoxic, and enzyme inhibitory effects (Dinh et al., 2022; Nguyen et al., 2026). Recent computational and experimental studies have further highlighted the potential of its phytochemicals as anticancer agents, particularly as inhibitors of cyclin-dependent kinase 2 (CDK2), an important target in cancer therapy (May, Nguyen, 2026). These findings emphasise the increasing scientific and economic importance of this species.

In Vietnam, *A. sagittifolius* occurs naturally across a wide range of ecological conditions, from low mountainous areas and midlands to plains (Do et al., 2006). Owing to its medicinal and economic value, the species has increasingly been cultivated in several regions of Vietnam, particularly in the Central Highlands and the South Central Coast, where local populations are selected and propagated for tuber production. However, cultivated planting materials are currently heterogeneous and largely derived from local, non-standardised sources. This lack of uniformity poses challenges for germplasm conservation, cultivation, and the consistent production of high-quality medicinal raw materials. As noted by Bhat et al. (2025), the systematic collection, characterisation, and evaluation of plant genetic resources are essential steps for crop improvement and the sustainable utilisation of plant biodiversity.

Furthermore, recent studies on extraction optimisation and the bioactivity of *A. sagittifolius* have highlighted the importance of selecting appropriate plant materials with desirable traits to maximise phytochemical yield and biological activity. Despite its high medicinal value, *A. sagittifolius* remains relatively unused and insufficiently characterised, particularly with respect to its phenotypic diversity and germplasm structure (Nguyen et al., 2024).

Therefore, this study aimed to establish a comprehensive morphological descriptor dataset and evaluate phenotypic diversity among twenty *A. sagittifolius* accessions collected from different ecological regions of Vietnam, thereby providing a baseline resource for future research, germplasm conservation, and breeding programmes.

Materials and methods

Plant materials

Twenty accessions of *Abelmoschus sagittifolius* were collected from cultivated populations located in ten provinces and cities (nine administrative units after consolidation) representing six ecological regions of Vietnam (Tab. 1).

Tab. 1. List of *Ablemoschus sagittifolius* (Kurz) Merr. accessions used in the study

No.	Accession code	Collection locality (province/city)	Administrative unit after consolidation	Ecological region*	Collection date	Collected material
1	BC1	Dak Lak	Dak Lak	5	December 2022	Seeds
2	BC2	Dak Lak	Dak Lak	5	December 2022	Seeds
3	BC3	Dak Lak	Dak Lak	5	December 2022	Seeds
4	BC4	Dak Lak	Dak Lak	5	December 2022	Seeds
5	BC5	Dak Lak	Dak Lak	5	December 2022	Seeds
6	BC6	Dak Lak	Dak Lak	5	December 2022	Seeds
7	BC7	Hanoi	Hanoi	2	November 2022	Seeds
8	BC8	Hanoi	Hanoi	2	November 2022	Seeds
9	BC9	Lao Cai	Lao Cai	1	February 2023	Seeds
10	BC10	Lam Dong	Lam Dong	5	December 2022	Seeds
11	BC11	Nghe An	Nghe An	3	December 2022	Seeds
12	BC12	Phu Yen	Dak Lak	4	December 2022	Seeds
13	BC13	Phu Yen	Dak Lak	4	December 2022	Seeds
14	BC14	Quang Binh	Quang Tri	4	December 2022	Seeds
15	BC15	Thanh Hoa	Thanh Hoa	3	February 2023	Seeds
16	BC16	Thanh Hoa	Thanh Hoa	3	February 2023	Seeds
17	BC17	Tay Ninh	Tay Ninh	6	December 2022	Seeds
18	BC18	Vinh Phuc	Phu Tho	1	October 2022	Seeds
19	BC19	Vinh Phuc	Phu Tho	1	October 2022	Seeds
20	BC20	Vinh Phuc	Phu Tho	1	October 2022	Seeds

*Ecological regions of Vietnam: 1 – northern midlands and mountainous region (mountainous area with a subtropical climate, cooler temperatures, and high topographic diversity), 2 – Red River Delta (lowland alluvial plain with intensive agriculture and a humid tropical monsoon climate), 3 – north central region (transitional zone with a tropical monsoon climate), 4 – south central coast (coastal region characterised by dry conditions, sandy soils, and strong seasonal variation), 5 – Central Highlands (highland plateau with fertile basaltic soils and a cooler tropical climate), 6 – southeast region (lowland tropical region with warm temperatures, relatively stable climate, and intensive cultivation systems).

Seed samples representing each accession were randomly collected from medicinal plant cultivation gardens maintained by local farmers and research collections. For each accession, seeds were collected from 15–20 mature plants to capture phenotypic variation within the cultivated populations. After collection, the seed material was cleaned, air-dried, labelled, and

stored at 4 °C in a refrigerator at the National Research Center for Medicinal Plant Germplasm and Breeding (NCGB).

Field experiments were conducted at the NCGB, Thanh Tri commune, Hanoi, from February to December 2023.

Field experimental design

The accessions were arranged in a non-replicated randomised germplasm evaluation trial. Each accession was planted on a 5 m² plot, with a total experimental area of 100 m². Cultivation practices followed the standard medicinal plant cultivation protocol of the *National Institute of Medicinal Materials* (*NIMM*, 2013).

Seed preparation and pre-sowing treatment: Seeds were subjected to pre-sowing treatment prior to sowing. Seeds were sun-dried under mild sunlight for 1–2 h, then soaked in warm water at 45–50 °C for 1–2 h. After soaking, seeds were rinsed with clean water, drained, and then incubated under warm conditions for 2–3 days. During incubation, seeds were washed daily with clean water and re-incubated after draining. When seeds exhibited radicle protrusion with creamy-white emergence, they were directly sown in the medicinal crop production field.

Sowing time: March 2023.

Soil selection: *A. sagittifolius* is best adapted to humus-rich, loose, well-aerated soils with a deep topsoil layer, good drainage capacity, and full sunlight exposure.

Land preparation: The soil was thoroughly tilled and left for aeration. Raised beds were prepared, of 25–30 cm high and of 80–100 cm wide; furrows were approximately 30 cm wide.

Planting density and spacing: Planting was conducted at a spacing of 20×15 cm, corresponding to a density of approximately 333,000 plants per hectare.

Fertilisation regime: Basal fertilisation consisted of 4 tons of bio-organic fertiliser per hectare, combined with 500 kg of NPK fertiliser (5:8:5) and 300 kg of urea (equivalent to 138 kg N).

Sowing technique and crop management: Transverse furrows were made across the bed surface at a depth of 7–10 cm and at intervals of 30–40 cm. Fertilisers were mixed into the furrows, and 10–12 seeds were sown per furrow. Seeds were covered with approximately 2 cm of soil and mulched with rice husk. Daily irrigation was applied to maintain adequate soil moisture. At temperatures of 21–26 °C, seed germination occurred within 7–10 days. Two to three weeks after emergence, thinning was performed to ensure a final intra-row spacing of 25–

30 cm. Weeding and soil crust breaking were carried out simultaneously, followed immediately by irrigation. During flowering, flower buds were removed when seed production was not required, in order to enhance assimilate allocation to tuber development.

Harvesting: Harvesting was conducted when plants showed leaf yellowing and senescence. On sunny days, tubers were collected, and aerial parts (stems and leaves) were removed prior to processing.

Sampling and data collection

Sampling schedule: Morphological data collection was conducted at multiple growth stages. 90 days after planting, samples were collected to evaluate and describe stem and leaf morphological traits. Floral, fruit, and seed characteristics were recorded 150–240 days after planting. Tuber-related traits were assessed 300–330 days after planting.

Sampling method: Data were collected from 10 plants per accession using a five-point diagonal sampling method.

Morphological measurement instruments: Morphological traits were measured using standard field methods, including a ruler for larger structures, a handheld micrometer caliper (±0.1 cm accuracy) for smaller plant organs, and a stereomicroscope (Olympus) connected to a computer for detailed observation and precise measurement of fine morphological features.

Morphological evaluation

The comparative morphological study was conducted following the methods described by Nguyen (2007) and Pham et al. (2021) regarding the morphological and microanatomical features of *A. sagittifolius* in Vietnam. The botanical characteristics and medicinal value of *A. sagittifolius* was carried out according to the methods described by Nguyen et al. (2024) and the morphological characteristics of the genus *Abelmoschus* following Patil et al. (2015).

A total of seven groups of characters comprising 26 diagnostic traits were recorded and analysed, including: growth habit (growth type and plant height), stem morphology (branching pattern and stem pubescence density), tuberous root morphology (tuber length, tuber diameter, and tuber fresh weight), leaf morphology (petiole colour, leaf blade shape and colour, vein colour, leaf margin shape, and stipule shape), floral morphology (colour of the adaxial petal surface, colour of the abaxial petal surface, colour of the petal base, petal shape, number of

epicalyx segments, density of staminal filaments, and stigma colour); fruit morphology (fruit shape, fruit length, fruit width, fruiting pedicel colour, and epicalyx colour at fruiting stage); and seed shape. Selected features were documented with photographs (Fig. 1 – Appendix 1).

Data analysis

Basic descriptive statistics were performed using Microsoft Excel 2010. Quantitative traits were expressed as mean ± standard deviation (SD) based on measurements of 10 plants representing each accession. The present study was designed as a preliminary non-replicated germplasm evaluation trial; therefore, statistical interpretation was primarily based on descriptive variation among individual plants within each accession.

For phenetic analysis, both quantitative and qualitative morphological traits were included. Quantitative variables were standardised prior to analysis in order to reduce scale effects among characters. Phenetic relationships among accessions were evaluated using the Unweighted Pair Group Method with Arithmetic Mean (UPGMA) (Sokal, Michener, 1958) implemented in NTSYS-pc version 2.1. The similarity matrix was generated from 26 morphological traits, including both measurable and descriptive characters.

Results and discussion

Morphological characteristics

Morphological characteristics is fundamental for species identification and crop improvement. Accordingly, comprehensive evaluation of plant traits and the establishment of a complete morphological dataset provides an essential foundation for subsequent studies on species identification, selection, and propagation. The main characteristics of the 20 collected *Abelmoschus sagittifolius* accessions can be summarised as follows:

Life form and habit – perennial herb. Most accessions were erect to semi-procumbent, whereas procumbent habits were recorded in BC12 and BC13. Plants were 20–60 cm tall, occasionally taller. Stems were slender and cylindrical, densely (BC15, BC17) or very densely (BC3–12) to sparsely (BC1–2, BC13–14, BC16, BC18–20) covered with stiff, coarse hairs; the surface was scabrous (Tab. 2 – Appendix 2).

Root – tuberous, cylindric and fleshy, white to pale yellow, 2.4–3.2 cm in diameter and 22–28 cm long (Tab. 3).

Tab. 3. Growth and yield-related traits of *Abelmoschus sagittifolius* (Kurz) Merr. accessions; BC1-BC20 – accession codes. Values are presented as mean ± SD (n = 10 plants per accession)

Accession	Plant height (cm)	Fruit length (cm)	Fruit width (cm)	Tuber length (cm)	Tuber diameter (cm)	Tuber fresh weight (g/plant)
BC1	41.60 ± 3.93	3.26 ± 0.13	2.42 ± 0.27	25.00 ± 0.31	2.74 ± 0.57	180.00 ± 1.45
BC2	55.30 ± 4.03	3.24 ± 0.09	2.44 ± 0.31	28.30 ± 1.55	2.48 ± 0.44	175.30 ± 1.34
BC3	37.98 ± 2.91	3.32 ± 0.55	2.40 ± 0.22	25.52 ± 2.25	2.76 ± 0.36	183.00 ± 1.68
BC4	36.50 ± 2.93	3.20 ± 0.22	2.40 ± 0.22	24.80 ± 2.43	2.80 ± 0.34	184.00 ± 1.57
BC5	40.00 ± 2.91	3.20 ± 0.22	2.36 ± 0.13	25.98 ± 2.45	2.80 ± 0.67	182.80 ± 2.24
BC6	46.98 ± 3.23	3.42 ± 0.27	2.36 ± 0.13	26.20 ± 1.59	2.48 ± 0.44	176.40 ± 1.34
BC7	53.02 ± 3.22	3.20 ± 0.27	2.40 ± 0.45	27.52 ± 2.24	2.58 ± 0.33	174.80 ± 1.12
BC8	59.00 ± 2.36	3.20 ± 0.22	2.50 ± 0.22	26.98 ± 2.25	2.60 ± 0.22	177.32 ± 1.47
BC9	54.00 ± 4.82	3.20 ± 0.22	2.40 ± 0.22	26.38 ± 2.24	2.70 ± 0.45	174.50 ± 1.00
BC10	56.00 ± 3.69	3.24 ± 0.31	2.34 ± 0.09	26.78 ± 2.22	2.60 ± 0.33	176.20 ± 1.57
BC11	54.00 ± 3.68	3.34 ± 0.31	2.36 ± 0.13	27.62 ± 1.34	2.80 ± 0.32	173.80 ± 1.23
BC12	20.40 ± 2.37	3.24 ± 0.31	2.34 ± 0.09	22.00 ± 2.45	3.12 ± 0.43	201.30 ± 2.46
BC13	21.80 ± 3.48	3.20 ± 0.22	2.36 ± 0.13	21.98 ± 1.99	3.20 ± 0.24	199.00 ± 2.01
BC14	34.00 ± 2.36	3.24 ± 0.31	2.36 ± 0.36	25.50 ± 2.32	2.70 ± 0.25	186.00 ± 2.01
BC15	52.00 ± 2.36	3.26 ± 0.36	2.40 ± 0.34	25.90 ± 1.67	2.80 ± 0.24	171.60 ± 1.23
BC16	54.62 ± 2.34	3.26 ± 0.13	2.34 ± 0.09	26.80 ± 1.65	2.50 ± 0.23	171.20 ± 1.23
BC17	52.90 ± 2.8	3.30 ± 0.22	2.34 ± 0.09	26.80 ± 2.23	2.62 ± 0.43	173.00 ± 1.68
BC18	56.02 ± 2.79	3.28 ± 0.24	2.40 ± 0.22	26.72 ± 1.15	2.68 ± 0.47	173.20 ± 1.45
BC19	48.20 ± 3.78	3.30 ± 0.22	2.38 ± 0.18	27.02 ± 1.46	2.42 ± 0.22	173.50 ± 1.56
BC20	51.10 ± 2.35	3.20 ± 0.22	2.46 ± 0.13	27.68 ± 1.43	2.40 ± 0.32	174.00 ± 1.45

Leaves – simple, alternate; stipules linear, filiform, pubescent, caducous. Leaf blades variable in shape: shallowly to deeply palmately 3–5-lobed in accessions such as BC1, BC5–BC12, BC14–BC17, whereas lanceolate leaves predominated in BC2–BC4, BC13, BC18–BC20. Margins evenly and sparsely serrate. Both surfaces were covered with stiff hairs. Venation palmate. Leaf blades 4–6(–9)×2–5(–6.5) cm. Petioles 3–9.5 cm long, with colour varying from green to reddish (Tab. 2. – Appendix 2).

Flowers – solitary in leaf axils or arranged in axillary or terminal racemes. Pedicels 4.5–7 cm long, densely hispid. Flowers 4.5–5.5 cm in diameter. Epicalyx segments 7–8 (e.g. BC3) up to 11 (BC20), linear to lanceolate, 0.8–1.5 cm long, densely hairy, apically with few small teeth. Calyx of five spatulate lobes, connate, irregularly lobed and caducous, 14–18 mm long, minutely puberulent. Aestivation contorted. Corolla of five free petals, obovate (BC4, BC13) to cuneate (BC1–12, BC14–20), 4–6×2.5–4 cm; petal colour red (BC1–3, BC7–12, BC14–19), yellow (BC4–6, BC20), or pale pink (BC13), with the inner basal region yellowish (BC1–3), dark red (BC13), red (BC20), white (BC8–12, BC14–19), or pale pink (BC4–7). Stamens monadelphous,

filaments completely united into a cylindrical staminal column 1.2–2 cm long; anthers covering the column to its base, glabrous. Gynoecium composed of five united carpels forming a superior ovary; ovary ovoid, 5-locular, with axile placentation, densely hairy externally. Style single, with five stigma lobes; stigma branches bright red, dark red, or yellow (Tab. 4. – Appendix 2).

Fruit – capsule ovoid-lanceolate or lanceolate (BC3–BC6, BC10, BC13) to broadly ovoid (BC1–2, BC7–BC9, BC19–20), longitudinally ribbed; calyx persistent until fruit maturity. At maturity, the pericarp dries and dehisces loculicidally into five valves. Fruit surface densely covered with stellate hairs on both sides. Capsule 3-3.5×2-2.5 cm; fruiting pedicel 4-9 cm long; fruit green or reddish (Tab. 4. – Appendix 2).

Seeds – reniform to subglobose in all accessions, 2–3 mm long, pubescent; pale yellow when immature and dark brown to black at maturity. Seed coat with regular reticulate striations; hilum pubescent (Tab. 4. – Appendix 2).

Based on the morphological descriptions, all *A. sagittifolius* accessions exhibited the diagnostic features of the species, including herbaceous structure; slender, cylindrical stems and branches densely covered with stiff hairs; tuberous, cylindric, fleshy, roots ranging in colour from white to pale yellow; and seeds reniformed to subglobose, 2–3 mm long, pubescent, dark brown to black at maturity, with regular surface striations and a pubescent hilum.

However, owing to the species' wide natural distribution range, considerable phenotypic variation was observed among the collected accessions, particularly in traits related to life form, and the shape and colour of flowers and leaves. These findings are consistent with previous descriptions reported by Phan et al. (2005), Pham et al. (2021), and Nguyen et al. (2024).

According to the data presented in table 3, plant height ranged from 20.40 to 59.00 cm; fruit length varied from 3.20 to 3.42 cm; and fruit width ranged from 2.34 to 2.50 cm. With respect to root traits, the accessions exhibited tuber cluster lengths of 21.98–28.30 cm, tuber diameters of 2.40–3.20 cm, and individual tuber fresh weights ranging from 171.20 to 201.30 g. These results are in agreement with those reported by Nguyen et al. (2020, 2021). Among the evaluated accessions, BC12 had the highest tuber fresh weight (201.30 ± 2.46 g/plant), followed by BC13 (199.00 ± 2.01 g/plant), both originating from Phu Yen. These two accessions also showed relatively large tuber diameters, especially BC13, which reached the maximum recorded value of 3.20 ± 0.24 cm. Interestingly, both BC12 and BC13 had the lowest plant height values, suggesting that reduced above-ground growth may be associated with greater assimilate

allocation to tuber development. Since the tuberous root is the principal medicinally used part of *A. sagittifolius*, these accessions are particularly valuable for future selection and breeding programmes aimed at improving tuber yield. However, because the present study was conducted as a single-location germplasm evaluation trial, further multi-location and replicated field experiments are needed to confirm the stability of these yield-related traits.

Phenotypic diversity among accessions based on phenotypic traits

Phenetic relationships among the 20 *A. sagittifolius* accessions were assessed based on 26 phenotypic traits, including plant height, fruit length, fruit width, root length, root diameter, root fresh weight, life form, branching pattern, stem pubescence density, stipule shape, petiole colour, leaf blade shape, leaf blade colour, leaf margin type, colour of the adaxial petal surface, colour of the abaxial petal surface, colour of the petal base, petal shape, number of epicalyx segments, density of staminal filaments, stigma colour, fruit shape, fruit apex shape, fruiting pedicel colour, epicalyx colour at fruiting stage, and seed shape.

The results of the analysis of similarity coefficients between 20 accessions of *A. sagittifolius* using the UPGMA method are presented in table 5.

Tab. 5. Similarity matrix and phenetic relationships among 20 *Abelmoschus sagittifolius* (Kurz) Merr. accessions based on 26 morphological traits analysed using the UPGMA clustering method. Morphological data were obtained from 10 plants per accession. BC1–BC20 – accession codes

	BC1	BC2	BC3	BC4	BC5	BC6	BC7	BC8	BC9	BC10	BC11	BC12	BC13	BC14	BC15	BC16	BC17	BC18	BC19	BC20
BC1	1.00																			
BC2	0.46	1.00																		
BC3	0.31	0.46	1.00																	
BC4	0.31	0.31	0.42	1.00																
BC5	0.27	0.23	0.42	0.58	1.00															
BC6	0.23	0.42	0.31	0.50	0.54	1.00														
BC7	0.46	0.35	0.31	0.27	0.31	0.38	1.00													
BC8	0.54	0.42	0.31	0.27	0.31	0.31	0.69	1.00												
BC9	0.54	0.42	0.35	0.31	0.31	0.31	0.65	0.73	1.00											
BC10	0.46	0.38	0.31	0.23	0.23	0.35	0.58	0.65	0.65	1.00										
BC11	0.42	0.46	0.38	0.23	0.35	0.27	0.42	0.54	0.54	0.54	1.00									
BC12	0.35	0.35	0.27	0.23	0.27	0.23	0.38	0.42	0.46	0.54	0.46	1.00								
BC13	0.31	0.35	0.31	0.38	0.23	0.31	0.19	0.23	0.23	0.19	0.27	0.31	1.00							
BC14	0.35	0.42	0.35	0.23	0.23	0.35	0.35	0.35	0.38	0.46	0.38	0.46	0.31	1.00						
BC15	0.38	0.38	0.31	0.38	0.27	0.27	0.42	0.46	0.50	0.50	0.58	0.50	0.19	0.46	1.00					
BC16	0.50	0.42	0.31	0.19	0.27	0.19	0.38	0.50	0.50	0.54	0.62	0.54	0.27	0.46	0.58	1.00				
BC17	0.35	0.38	0.38	0.15	0.23	0.15	0.38	0.50	0.50	0.54	0.65	0.50	0.23	0.38	0.50	0.73	1.00			
BC18	0.31	0.50	0.38	0.27	0.12	0.23	0.31	0.38	0.42	0.38	0.46	0.42	0.35	0.46	0.46	0.50	0.50	1.00		
BC19	0.35	0.50	0.27	0.19	0.15	0.42	0.42	0.42	0.42	0.42	0.35	0.31	0.23	0.54	0.38	0.38	0.35	0.54	1.00	
BC20	0.27	0.42	0.19	0.31	0.27	0.50	0.38	0.35	0.35	0.31	0.23	0.23	0.23	0.42	0.27	0.27	0.19	0.35	0.58	1.00

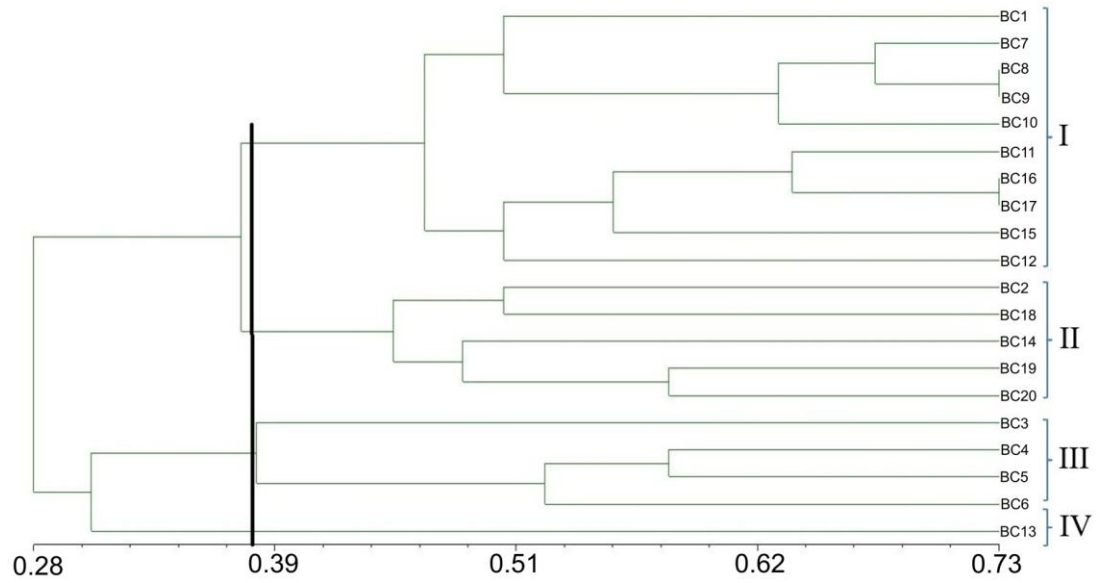

Fig. 2. Phenetic relationship dendrogram of 20 *Abelmoschus sagittifolius* (Kurz) Merr. accessions constructed using the UPGMA clustering method based on 26 morphological traits. Morphological data were obtained from 10 plants per accession. BC1–BC20 – accession codes; I–IV – phenetic groups; the black vertical line indicates the average similarity coefficient (0.38)

Similarity coefficients reflect the phenetic relationships among the studied accessions, with higher values indicating closer phenetic relationships and lower values indicating greater phenetic divergence. The similarity coefficients ranged from 0.12 (between accessions BC5 and BC18) to 0.73 (between accessions BC8 and BC9, and between BC16 and BC17).

At an average similarity coefficient of 0.38, a phenetic relationship dendrogram was constructed and divided into four major clusters (Fig. 2).

+ **Group I** comprised accessions BC1, BC7, BC8, BC9, BC10, BC11, BC12, BC15, BC16, and BC17. This group shared several common morphological features, including basal branching; long, linear stipules; slightly reddish petioles; predominantly palmately 5-lobed leaves; green leaf blades with slightly reddish veins; and evenly serrate leaf margins. Flowers generally exhibited red adaxial petal surfaces, a medium density of staminal filaments, and bright red stigmas. Fruits were broadly ovoid with an acute apex, and seeds were reniform to subglobose. Accessions in this group were widely distributed across all three regions of Vietnam, representing diverse ecological conditions, including Dak Lak, Hanoi, Lao Cai, Lam Dong, Nghe An, Phu Yen, Thanh Hoa, and Tay Ninh.

+ **Group II** included accessions BC2, BC14, BC18, BC19, and BC20. Accessions in this group were characterised mainly by evenly branched stems, sparse stem pubescence, short linear stipules, slightly reddish petioles, and predominantly lanceolate leaves with green blades and evenly serrate margins. Flowers showed a high density of staminal filaments and bright red stigmas. Fruits were broadly ovoid with an acute apex, and seeds were reniform to subglobose. This group was distributed across several regions, including Dak Lak, Quang Binh, and Vinh Phuc.

+ **Group III** consisted of accessions BC3, BC4, BC5, and BC6. These accessions generally exhibited a semi-procumbent growth habit, basal branching, dense stem pubescence, lanceolate leaves with green blades and evenly serrate margins. Flowers possessed cuneate petals, eight epicalyx segments, and a high density of staminal filaments. Fruits were ovoid-lanceolate with an acute apex, and seeds were reniform. All accessions in this group were collected from Dak Lak province.

+ **Group IV** comprised a single accession, BC13, which displayed the most distinct morphological featuress, particularly floral shape and colour. This accession exhibited a procumbent growth habit, basal branching, sparse stem pubescence, short linear stipules, slightly reddish petioles, lanceolate leaves with green blades and evenly serrate margins. Flowers had broadly obovate petals with pale pink colouration on both adaxial and abaxial surfaces, a red basal region on the adaxial surface, eight epicalyx segments, a medium density of staminal filaments, and dark red stigmas. Fruits were ovoid-lanceolate to broadly ovoid with an acute to slightly obtuse apex, and seeds were reniform. This accession was collected from Phu Yen province.

Overall, based on the 20 collected accessions and the evaluated morphological traits, no clear grouping pattern corresponding to ecological or geographical distribution was observed. This may be attributed to the species' wide ecological adaptability and high potential for natural hybridisation, as well as the movement of genetic material through selection and propagation practices among different cultivation regions. Due to its ease of cultivation and adaptability, *A. sagittifolius* can grow spontaneously in many areas and is widely cultivated on a large scale across Vietnam for medicinal purposes. In addition, the species is also distributed in other tropical and subtropical countries within the region.

Notably, accession BC13 collected from Phu Yen exhibited relatively distinct morphological features compared with the remaining accessions. Together with BC12, this accession also displayed superior tuber-related traits, particularly tuber fresh weight and tuber diameter. Because the tuberous root constitutes the principal medicinal and commercial organ of *A. sagittifolius*, tuber fresh weight may be regarded as one of the most important phenotypic criteria for future selection and cultivation. Therefore, BC12 and BC13 represent promising germplasm resources for breeding programmes aimed at improving tuber yield and medicinal production. Nevertheless, further molecular and phytochemical studies are required to verify the genetic basis and medicinal potential of these accessions.

Conclusions and recommendations

The present study revealed substantial phenotypic diversity among Vietnamese germplasm accessions of *Abelmoschus sagittifolius*, indicating the existence of valuable genetic resources for conservation and breeding. Despite the broad ecological distribution of the sampled materials, no clear relationship was observed between phenetic grouping and ecological or geographical origin, suggesting that phenotypic variation may reflect both environmental adaptation and long-term exchange of planting materials among cultivation regions.

Among the evaluated materials, tuber-related traits, particularly tuber fresh weight, appear to be the most important phenotypic criteria for future selection and cultivation because the tuberous root represents the principal medicinal and commercial organ of the species. Accessions BC12 and BC13 (Phu Yen) showed superior tuber performance and therefore constitute promising germplasm resources for the development of high-yielding cultivars. In addition, BC13 exhibited marked morphological distinctiveness and may represent valuable material for further taxonomic and breeding studies.

Future research integrating molecular markers, phytochemical profiling, and multi-location evaluation is recommended to clarify the genetic relationships and medicinal potential of these promising accessions.

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Conflict of interest

The authors declare no conflict of interest related to this article.

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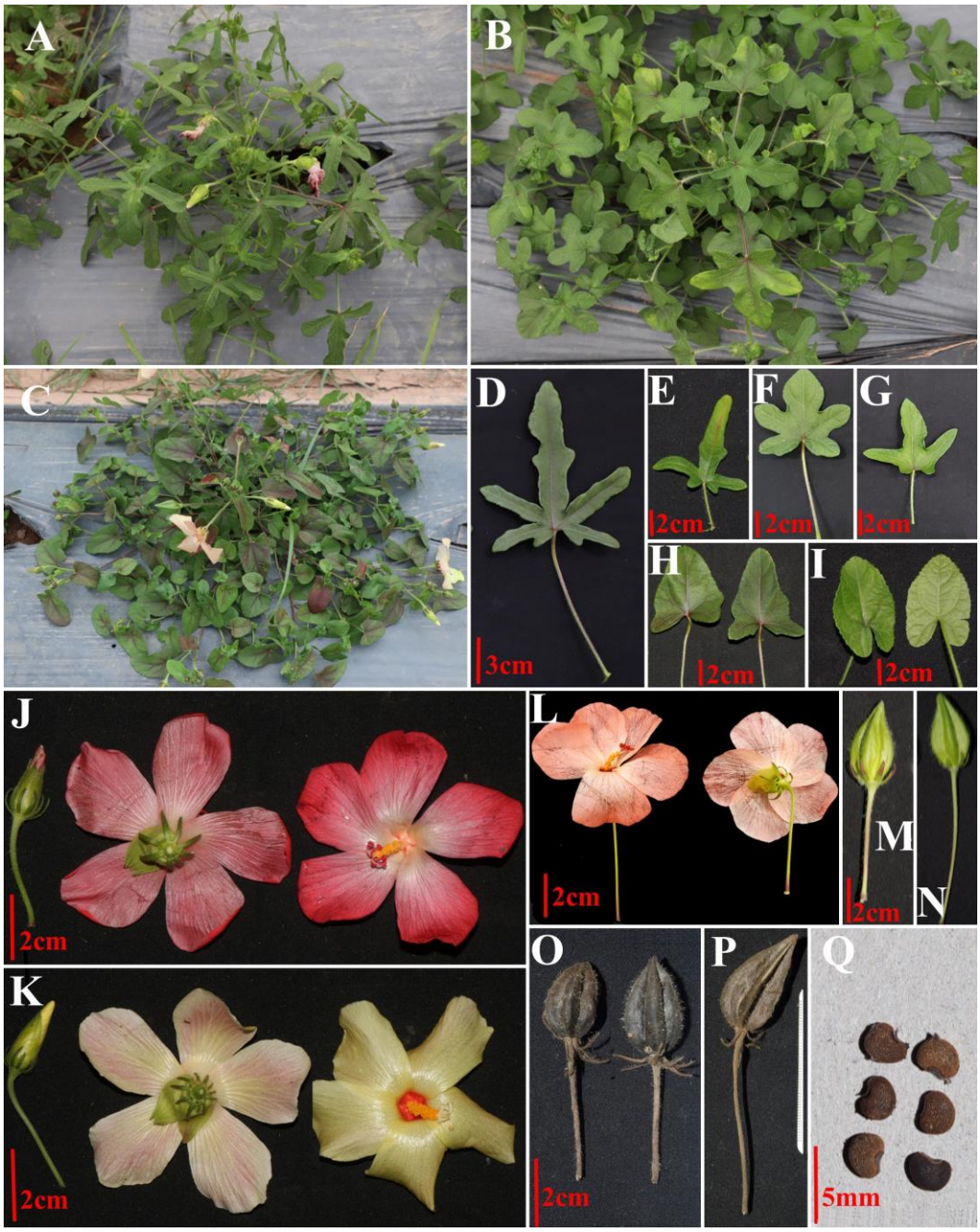

Fig. 1. Selected morphological features of *Abelmoschus sagittifolius* (Kurz) Merr.; variation in life form: erect (A), semi-procumbent (B), and procumbent habits (C); variation in leaf morphology: deeply palmately 3–5-lobed (D-E), shallowly palmately 3–5-lobed (F-G), and lanceolate leaves (H-I); variation in flower morphology: flower bud, abaxial and adaxial views of flowers of the red-flowered form (J); flower bud, abaxial and adaxial views of flowers of the yellow-flowered form (K); adaxial and abaxial views of flowers of the pink-flowered form (L); fruit morphology: capsule at the immature stage (M,N) and at maturity (O, P); and seeds (Q) (Photo. M.T. To and T.G. Dinh)

Tab. 2. Vegetative morphological characters of *Abelmoschus sagittifolius* (Kurz) Merr. accessions; BC1-BC20 – accession codes (n = 10 plants per accession)

Accession	Growth habit	Branching pattern	Stem pubescence density	Stipule shape	Petiole colour	Leaf			
						Blade shape	Colour	Vein colour	Leaf margin
BC1	Semi-procumbent	Branched at base	Sparse	Long linear	Green or reddish	Shallowly 3–5-lobed or lanceolate	Green	Reddish	Undulate
BC2	Erect	Evenly branched	Sparse	Short linear	Green or reddish	Lanceolate	Green	Green	Undulate
BC3	Semi-procumbent	Branched at base	Very dense	Short linear	Green	Lanceolate	Green	Green	Undulate
BC4	Semi-procumbent	Branched at base	Very dense	Short linear	Reddish	Lanceolate	Green	Reddish	Undulate
BC5	Semi-procumbent	Branched at base	Very dense	Long linear	Green	Lanceolate or shallowly 3-lobed	Green	Reddish	Undulate
BC6	Semi-erect	Branched at base	Very dense	Short linear	Reddish	Deeply 3–5-lobed	Green	Reddish	Undulate
BC7	Erect	Branched at base	Very dense	Long linear	Reddish	Deeply 3–5-lobed	Green	Reddish	Undulate
BC8	Erect	Branched at base	Very dense	Long linear	Reddish	Deeply 3–5-lobed	Green	Reddish	Undulate
BC9	Erect	Branched at base	Very dense	Long linear	Reddish	Deeply 5-lobed	Green	Reddish	Undulate
BC10	Erect	Branched at base	Very dense	Long linear	Reddish	Deeply 5-lobed	Green	Reddish	Undulate
BC11	Erect	Evenly branched	Very dense	Long linear	Green	Shallow or deeply 5-lobed	Green	Green	Undulate
BC12	Procumbent	Evenly branched	Very dense	Long linear	Reddish	Deeply 5-lobed	Green	Reddish	Undulate
BC13	Procumbent	Branched at base	Sparse	Short linear	Reddish	Lanceolate	Green	Green	Undulate
BC14	Semi-procumbent	Evenly branched	Sparse	Short linear	Green or reddish	Deeply 5-lobed or lanceolate	Green	Reddish	Undulate
BC15	Erect	Evenly branched	Dense	Long linear	Reddish	Shallow or deeply 5-lobed	Green	Reddish	Undulate
BC16	Erect	Evenly branched	Sparse	Long linear	Green	Shallow or deeply 3–5-lobed	Green	Reddish	Undulate
BC17	Erect	Evenly branched	Dense	Long linear	Green	Shallow or deeply 5-lobed	Green	Green	Undulate

Accession	Growth habit	Branching pattern	Stem pubescence density	Stipule shape	Petiole colour	Leaf			
						Blade shape	Colour	Vein colour	Leaf margin
BC18	Erect	Evenly branched	Sparse	Short linear	Green or reddish	Lanceolate	Green	Green	Undulate
BC19	Erect	Evenly branched	Sparse	Short linear	Reddish	Lanceolate	Green	Reddish	Undulate
BC20	Erect	Evenly branched	Sparse	Short linear	Reddish	Lanceolate	Green	Reddish	Undulate

Tab. 4. Reproductive morphological characters of *Abelmoschus sagittifolius* (Kurz) Merr. accessions; BC1-BC20 – accession codes (n = 10 plants per accession)

Accession	Flower							Fruit			Seed shape
	Petal shape	Adaxial petal colour	Abaxial petal colour	Petal base colour	No. of epicalyx segments	Stamen density	Stigma colour	Fruit shape	Pedicel colour	Epicalyx colour	
BC1	Cuneate	Red	Pale pink	Yellowish	8	Medium	Bright red	Broadly ovoid, acute	Green	Green	Reniform
BC2	Cuneate	Red	Pale pink	Yellowish	8	Dense	Bright red	Broadly ovoid, acute	Green	Green	Reniform to subglobose
BC3	Cuneate	Red	Pale pink	Yellowish	7–8	Dense	Bright red	Ovoid to lanceolate	Green	Green or reddish	Reniform to subglobose
BC4	Cuneate to obovate	Yellow	Yellow	Pale pink	8	Dense	Pale yellow	Ovoid to lanceolate	Green	Green	Reniform
BC5	Cuneate	Yellow	Yellow	Pale pink	8	Dense	Pale yellow	Lanceolate-ovoid	Green	Green or reddish	Reniform to subglobose
BC6	Cuneate	Yellow	Yellow	Pale pink	8	Dense	Pale yellow	Lanceolate	Reddish	Reddish	Reniform to subglobose
BC7	Cuneate	Red	Pale pink	Pale pink	8–9	Medium	Bright red	Broadly ovoid	Reddish	Green or reddish	Reniform to subglobose
BC8	Cuneate	Red	Pale pink	White	8–9	Medium	Bright red	Broadly ovoid	Green	Green	Reniform to subglobose
BC9	Cuneate	Red	Pale pink	White	8–10	Medium	Bright red	Broadly ovoid	Green	Green	Reniform to subglobose
BC10	Cuneate	Red	Pale pink	White	7–10	Medium	Bright red	Ovoid to lanceolate	Reddish	Green	Reniform to subglobose
BC11	Cuneate	Red	Pale pink	White	8	Medium	Bright red	Ovoid	Green	Green	Reniform to subglobose
BC12	Cuneate	Red	Pale pink	White	8	Sparse	Bright red	Ovoid to lanceolate	Green	Green	Reniform to subglobose
BC13	Obovate	Pale pink	Pale pink	Dark red	8	Medium	Dark red	Ovoid to lanceolate	Green	Reddish	Reniform
BC14	Cuneate	Red	Pale pink	White	10	Dense	Bright red	Ovoid	Reddish	Reddish	Reniform to subglobose
BC15	Cuneate	Red	Pale pink	White	8	Dense	Bright red	Ovoid	Reddish	Green	Reniform to subglobose
BC16	Cuneate	Red	Pale pink	White	8	Medium	Bright red	Ovoid	Green	Green	Reniform to subglobose
BC17	Cuneate	Red	Pale pink	White	10	Medium	Bright red	Ovoid	Green	Green	Reniform to subglobose

Accession	Flower							Fruit			Seed shape
	Petal shape	**Adaxial petal colour**	**Abaxial petal colour**	**Petal base colour**	**No. of epicalyx segments**	**Stamen density**	**Stigma colour**	**Fruit shape**	**Pedicel colour**	**Epicalyx colour**	
BC18	Cuneate	Red	Pale pink	White	9–10	Sparse	Pink	Ovoid	Green	Green	Reniform to subglobose
BC19	Cuneate	Red	Pale pink	White	9–10	Dense	Pink	Broadly ovoid	Reddish	Reddish	Reniform to subglobose
BC20	Cuneate	Yellow	Yellow-pink	Red	11	Dense	Pale yellow	Broadly ovoid	Reddish	Reddish	Reniform to subglobose

Morfologiczna charakterystyka oraz ocena zróżnicowania fenotypowego zasobów germplazmy *Abelmoschus sagittifolius* (Kurz) Merr. w Wietnamie

Streszczenie

Gromadzenie, ochrona oraz charakterystyka zasobów genetycznych roślin stanowią podstawę programów hodowlanych oraz rozwoju wysokowydajnych i wysokiej jakości systemów uprawy. W niniejszym badaniu oceniono dwadzieścia akcesji *Abelmoschus sagittifolius* (Kurz) Merr., reprezentujących populacje uprawne pochodzące z dziesięciu prowincji/miasta (dziewięciu jednostek administracyjnych po reformie) oraz sześciu regionów ekologicznych Wietnamu, w celu określenia zmienności morfologicznej oraz zależności fenetycznych pomiędzy akcesjami. Łącznie przeanalizowano 26 cech fenotypowych związanych z pokrojem roślin, morfologią łodyg, liści, kwiatów, owoców i nasion przy użyciu standaryzowanych terminów morfologicznych. Zależności fenetyczne oceniono na podstawie analizy skupień metodą UPGMA. Badane akcesje zostały podzielone na cztery główne grupy fenetyczne przy średniej wartości podobieństwa wynoszącej 0,38, natomiast wartości podobieństwa mieściły się w zakresie od 0,12 do 0,73. Stwierdzono znaczną zmienność zarówno cech wegetatywnych, jak i generatywnych, szczególnie w zakresie pokroju roślin, morfologii liści, barwy kwiatów oraz cech związanych z korzeniami spichrzowymi. Na szczególną uwagę zasługują akcesje BC12 i BC13 z prowincji Phu Yen, które wykazały najwyższą świeżą masę korzeni spichrzowych, osiągając odpowiednio 201,30 ± 2,46 oraz 199,00 ± 2,01 g/roślinę, przy czym akcesja BC13 wyróżniała się również największą odrębnością morfologiczną, zwłaszcza pod względem morfologii kwiatów i pokroju roślin. Nie stwierdzono wyraźnej zależności pomiędzy grupowaniem fenetycznym a rozmieszczeniem ekologicznym, co sugeruje, że obserwowana zmienność fenotypowa może odzwierciedlać zarówno adaptację środowiskową, jak i zróżnicowanie genetyczne. Uzyskane wyniki stanowią istotną podstawę dla ochrony zasobów germplazmy, badań taksonomicznych oraz przyszłej selekcji i hodowli wysokowydajnych odmian *A. sagittifolius* w Wietnamie.

Słowa kluczowe: Żeń-szeń Bo Chinh, cechy morfologiczne, charakterystyka fenotypowa, różowa malwa bagienna, metoda UPGMA.

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