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CHARACTERIZATION OF MORPHOLOGICAL DIVERSITY IN MARIGOLD (*Tagetes spp.)* ACCESSIONS IN SRI LANKA: A PRELIMINARY STUDY

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ABSTRACT

The study evaluated twenty-five marigolds (Tagetes spp.) accessions in Sri Lanka, identifying them taxonomically as T. erecta (African marigolds). Despite its increasing demand in Sri Lanka, there has been limited scientific assessment of the floral morphological variation in locally available marigold accessions, which is essential for guiding breeding, landscaping, and commercial applications. Marigold accessions were collected from various locations in Sri Lanka and cultivated at the Faculty of Agriculture, University of Ruhuna, Sri Lanka. All together ten traits were considered for the analysis including plant architecture, petal colour, flower diameter measurement, and morphological classification of disc and ray florets; Flowers were categorized into single, semi-double, double, and anemone types based on ray and disc floret arrangements. The accessions displayed a diverse range of flower colours, including ranges of colours in yellow and orange. Flowers were classified into three size categories: small (<3.9 cm), medium (3.9–4.9 cm), and large (>5 cm). Single-type flowers were observed in accessions 2, 8, 15, and 22, while semi-double appeared in accessions 1, 2, 3, 4, 11, 13, 18, 23, and 24. Accession 6 was double type and accessions 5, 6, 7, 10, 14, 17, and 21 were anemone-type flowers (featured prominent disc florets in all colour ranges). The floral trimorphism was recorded in accessions 22 and 24. Principal Component Analysis (PCA) revealed that the first three principal components accounted for 73.38% of the total phenotypic variation. PCA results showed that variation among marigold accessions was primarily influenced by traits related to floral productivity, and branching (PC1), as well as flower size and structure (PC2), highlighting their value as key descriptors for genetic diversity assessment and breeding selection. Hierarchical clustering using Ward's method grouped the 25 flower accessions into three distinct clusters, reflecting clear phenotypic differentiation based on the evaluated morphological traits. The constructed key can be utilized to distinguish studied marigold accessions in future. This floral diversity supports the development of cultivars suited to consumer preferences. Single and semi-double types can be promoted for biodiversity conservation and ecological sustainability, attracting pollinators in agroecosystems since they have a lot of disc florets for seed production. Meanwhile, double and anemone types can be commercially propagated for premium floriculture markets, enhancing economic value since they have attractive appearance.

Keywords: Marigold, Anemone, Double, Semi-double, Single flowers

Introduction

Tagetes, commonly called Marigolds, is a genus of nearly 50 species of herbaceous, flowering plants with a shrubby growth habit in the Asteraceae family. Native to Central and South America, the name marigold is derived from the contraction of Mary's gold, referencing its association with the Virgin Mary in Christianity and the golden colour of the flowers (Ward & Graha, 2023). In recent years, it has become increasingly popular as an ornamental garden plant, and many cultivars are available globally, differing in flower colour, size, and height (Heuzé et al., 2017). Marigold plants are used for a variety of purposes, including beverage and sauce production, ornamentals use, and medicinal applications such as antiseptics, analgesics, vermin repellents, carminatives, diuretics, antispasmodics, stimulants, and treatment of gastrointestinal disorders (Singh et al., 2016).

The genus Tagetes includes approximately 40 to 60 species of flowering plants, among which the African marigold (*T. erecta* L.) and French marigold (*T. patula* L.) are the most commercially significant. T. erecta is a tall, diploid species ($2n = 2x = 24$) that produces large, showy flowers and is widely used in landscape gardening and ceremonial decorations. In contrast, *T. patula* is a tetraploid ($2n = 4x = 48$) dwarf variety with compact growth and smaller flowers, often preferred for pot culture and borders. Another species, *T. minuta* (wild marigold), is valued for its high essential oil content (Gupta et al., 2022; Bhusaraddi et al., 2022)

The genus Tagetes includes approximately 40–60 species, African marigold (*Tagetes erecta* L.) and French marigold (*Tagetes patula* L.) are of commercial importance, while *Tagetes minuta* (wild marigold) is rich in essential oils (Gupta et al., 2022).

The marigold flowers, which are orange, yellow, and reddish-yellow (red), contain various pigments that can differ based on their source and soil type (Harlapur, 2021). Carotenoids are the primary pigments found in marigold flowers, and the variations in carotene (orange pigments) and xanthophyll (yellow pigments) levels among different genotypes play a significant role in the diversity of their flower colours (Zhang et al., 2020).

A previous study on African Marigolds revealed that the high heritability and low genetic gain for flowering duration and flower diameter suggest environmental factors rather than genetic ones primarily influence these traits. This indicates non-additive gene action, suggesting that environmental factors, too, play a crucial role in the morphology and physiology of the marigolds (Pal & Kumar, 2010).

Marigold has become popular because it rapidly produces marketable flowers and comes in a wide range of attractive colours, shapes, and sizes, along with good keeping quality. It holds a significant position in ornamental horticulture and is one of the world's most commercially valuable flower crops.

Understanding variability, genetic advancement, and heritability is crucial for supporting marigold breeding programs. Estimating the genetic coefficient of variation reveals the extent of genetic variation for various desirable traits. Genetic variability in breeding materials is vital for enhancing crop plants. This information aids in identifying suitable parental lines for breeding programs. Therefore, to make selection and improvement efforts effective, it is important to analyze and categorize the total variability in germplasm into genetic, phenotypic, and environmental components. This approach allows breeders to implement appropriate breeding strategies.

The diversity of marigold species adds to its beauty, ecological importance, and commercial potential in several ways. From an aesthetic standpoint, the array of marigold colours, ranging from bright yellows and oranges to reds and bi-coloured options, along with different flower shapes and sizes, creates a lively visual experience in gardens, landscapes, and floral displays. This variety also ensures that marigolds bloom continuously throughout the growing season, providing ongoing colour and texture (SL Flora, 2014).

Ecologically, marigolds are vital for attracting pollinators like bees and butterflies, and some species release natural substances that help repel pests, including soil-borne nematodes, which support healthier ecosystems. The diversity of marigolds also enhances soil health by improving pest management and decreasing the reliance on chemical pesticides. In commercial terms, marigolds are highly valued in the floral industry for their long-lasting, vibrant flowers, while essential oils derived from certain species are utilized in perfumes, cosmetics, and therapeutic products. Furthermore, their use in organic farming as companion plants for pest control adds to their agricultural significance. Marigolds' various forms and applications offer a rich resource supporting ecological sustainability and economic growth (Priyanka et al., 2013).

The global trade in marigold flowers is estimated at around Rs. 500 crores. China, India, and Peru are the top producers and exporters of marigold flowers, while the major importing countries include the USA and Europe (Mohan, 2016). The leading exporters of marigold flowers are India, Thailand, and China. With 4502 shipments, India leads the world in marigolds in flower exports, while Thailand and China export 1461 and 452 shipments, respectively. Marigold is the most grown and produced loose flower in India, followed by chrysanthemum, jasmine, tuberose, and Cassandra (Singh et al., 2016). In Sri Lanka, marigolds are often used as decorations at various ceremonies (Baghel Agro Industries., 2025). According to the Department of Agriculture, Peradeniya (2015), growing marigold alongside main crops like chilli, capsicum, and tomato can help reduce damage from the Heliothis pest by functioning as a trap crop. Additionally, Marigolds can repel soil-borne plant parasitic nematodes.

The literature reveals that marigold was introduced to Sri Lanka for ornamental purposes. It grows widely in-home gardens and is cultivated for cut flowers. While the plant is used for medicinal remedies and grown as a food crop in some other countries, it is used for horticultural purposes and Ayurvedic medicine in Sri Lanka (SL Flora, 2014). In Sri Lanka, marigolds are more commonly used as offerings and decorations at funerals, weddings, and various religious ceremonies. They are known for their durability and bloom in the fall (Baghel Agro Industries., 2025). Also, marigolds are used in commercialized herbal cosmetic products and plant pest and disease management practices in Sri Lanka (Gamage et al., 2021; Jayawardane, 2022). Statistical information about marigold cultivation in Sri Lanka is currently not available. However, in a previous study by Padmini and Kodagoda (2017), marigold was identified as a commonly grown ornamental plant in the local market.

Marigold accessions are essential for understanding this plant's genetic diversity, phenotypic variation, and soil adaptability. Marigolds come in various flower colours, sizes and growth habits. Some marigold cultivars have good drought-tolerant abilities (Dalman, 2022). These favourable characteristics in Marigolds are significant, making them valuable for breeding and commercial production.

Identifying and characterizing cultivars is essential for crop breeding and variety release programs (Korir et al., 2013). Characterization based on qualitative traits is particularly useful for identification due to the consistency of these traits across various environments (Srinivas & Rajasekharam, 2020). Systematic evaluation plays a key role in classifying and conserving marigold germplasm, providing vital information for crop improvement initiatives focused on enhancing yield, quality, and environmental adaptability. This thorough approach to trait analysis also facilitates the creation of standardized protocols for selecting and propagating top cultivars, ultimately supporting the sustainability and growth of the marigold industry.

Understanding genetic variation and the relationship among different genotypes is crucial for classifying and effectively using germplasm resources in marigold breeding (Kumar et al., 2019). Varietal identification based on morphological traits is sometimes too limited (Mor et al., 2008). In recent years, molecular marker technology has emerged as a valuable tool for developing new plant varieties (Hasan et al. 2021). Among the various types of molecular markers commonly used, the simple sequence repeat (SSR) or microsatellite marker is among the most effective and widely utilized (Mason, 2015). However, a few SSR markers have been developed for marigolds (Whankaew et al., 2014). Therefore, further morphological and molecular characterization is important for enhancing marigold breeding, conservation, and variety development.

There is a notable lack of research on the morphological diversity of marigolds in Sri Lanka, with few studies examining the full spectrum of genetic and phenotypic variation within the species. Gaining insight into this diversity is essential for breeding programs focused on enhancing marigold varieties to meet the unique environmental conditions and market needs of Sri Lanka. By filling this research gap, scientists can improve germplasm conservation, support the development of better varieties, and promote the sustainability of marigold farming in the area.

Comprehensive records on genetic diversity, better quality, disease resistance, and adaptability can support breeding programs by providing trustworthy data for selecting superior genotypes and helping create standardized varieties for commercial production. In the present study, marigold accessions were collected from diverse locations, evaluated and documented for the floral diversity to identify unique or promising flowers for future research and development.

MATERIALS AND METHODS

Study Site and Germplasm Collection

Twenty-five marigold (*Tagetes spp*.) accessions were collected from various agroecological zones across Sri Lanka. All accessions were established and evaluated at the Faculty of Agriculture, University of Ruhuna, located in the low country wet zone. This region offers favorable environmental conditions for marigold cultivation, including moderate temperatures, adequate sunlight, and high humidity, which support optimal growth and flowering performance.

Cultivation Conditions

The experiment was conducted under open-field conditions within a protected wire-mesh house to ensure sunlight exposure while minimizing disturbances from pests and animals. Seeds from each accession were sown in pots measuring 1 × 1 feet, filled with a potting mixture consisting of topsoil, compost, and sand in a 2:1:1 ratio. All seeds were sown simultaneously to ensure uniform germination. Thinning was performed at the four-leaf stage, retaining two healthy seedlings per pot. Ten pots were maintained for each accession, and standard agronomic practices such as irrigation, weeding, and pest management were applied uniformly throughout the cultivation period.

Experimental Design

The experiment followed a completely randomized design (CRD), with ten replicates per accession. Each replicate consisted of one pot containing two plants. Plants were raised inside a wire mesh house to protect them from the predators. Data were collected at the full bloom stage, and observations were made on both plants in each pot. Average values per plant were calculated and used for subsequent analysis.

Morphological Data Collection

At full bloom, ten vegetative and floral parameters were recorded. Plant height was measured from the base of the stem to the apex of the tallest branch. The number of main branches and total flowers per plant were also counted to assess floral productivity.

Floral Classification Criteria

Floral characterization was carried out using the first ten fully opened flowers on each plant. The dominant flower colour of each accession was visually identified using a standardized colour scale. The colours observed included pale yellow, light yellow-green, light yellow, yellow, bright yellow, golden yellow, yellow-orange, golden orange, reddish-orange, and reddish yellow.

The diameter of each flower was measured, and ray and disc florets were studied separately. The ray florets, positioned on the outer whorl of the composite flower head (capitulum), were categorized based on petal morphology including flat, frilled, reflexed, and serrated edges. Disc florets, located at the center of the flower head, were classified according to shape into tubular, bell-shaped, funnel-shaped, star-shaped, and compact forms.

Based on the visibility and arrangement of ray and disc florets, flowers were grouped into four floral types: single, semi-double, double, and anemone. Single-type flowers featured one row of ray florets surrounding a fully exposed disc, resembling a daisy (Table 1). Semi-double flowers had multiple rows of ray florets with disc florets still partially visible. Double-type flowers were composed of numerous layers of ray florets, entirely concealing the disc florets and giving a compact, rounded appearance. Anemone-type flowers were distinct for their prominent, enlarged disc florets forming a cushion-like central structure with few or no ray florets.

Table 1: Considered Characteristics for Floral Characteristics of Flower Type, Disc Florets Visibility, Ray Florets Layers, and Cross-Sectional Appearance

Type	Disc Florets	Ray florets	Appearance
S	Visible	One layer	Distinct discs and rays
SD	Partially visible	Multiple	Disc partially hidden
D	Not visible	Many	Dense, compact, rounded
A	Enlarged, dense, visible	Few or absent	Prominent cushion-like disc resembling an Anemone flower

S: Single, SD: Semi-double, Double, Anemone

Principal Component Analysis (PCA)

PCA was conducted to explore the structure of variation among flower accessions and to identify traits contributing most to diversity. The analysis was performed on the standardized dataset using the SPSS and R. Principal components were extracted based on eigenvalue decomposition of the correlation matrix. The proportion of variance explained by each component was calculated, and the first two principal components (PC1 and PC2) were used for visual interpretation. A biplot was generated to visualize both the position of accessions in the reduced space and the direction and strength of trait loadings. Hierarchical clustering using Ward’s method grouped the 25 flower accessions into distinct clusters, reflecting clear phenotypic differentiation based on the evaluated morphological traits.

RESULTS AND DISCUSSION

All the accessions recorded less than 130 cm in plant height. According to the taxonomic classification, the Sri Lankan Marigold type is *Targets erecta* (African marigolds). Generally, *T. erecta* is the tallest variety, growing between 90-120 cm high, with a sturdy upright growth (Table 2). *T. patula* exhibits a compact growth habit, growing to heights of 15-30 cm, making them ideal for growing in containers and borders. In contrast, Signet marigolds (*T. tenuifolia*) are much smaller, typically reaching heights of 15 cm or less (Dalman, 2022).

The flowers of the collected accessions recorded dominant and distinguishable colours: pale yellow, light yellow-green, yellow, bright yellow, golden yellow, yellow-orange, golden orange, reddish-orange, and reddish yellow (Table 2, Supplementary Figure 1). Carotenoids are the primary pigments found in marigold flowers, and the variations in carotene (which gives an orange hue) and xanthophyll (which provides a yellow shade) levels among different

Table 2: Floral characteristics of twenty-five marigold accessions

	Complete flower diameter (cm)	Disc florets diameter (cm)	Dominant colour	Compendium shape	Disc floret type	Ray floret type
1	5.01	2.69	Reddish Yellow	Semi-double	Tubular	Frilled
2	3.44	3.44	Bright yellow	Semi-double	Tubular	Flat
3	3.3	1.1	Yellow	Semi-double	Tubular	Frilled
4	5.02	1.3	Yellow	Semi-double	Tubular	Frilled, reflexed
5	5.01	5.01	Yellow orange	Anemone	Star	-
6	5.8	5.8	Pale yellow	Anemone	Star	-
7	5.7	5.7	Golden yellow	Anemone	Star	-
8	3.8	1.25	Light yellow	Single	Funnel	Frilled
9	5.5	4.0	Golden orange	Single	Star	Frilled, reflexed
10	3.8	3.8	Golden orange	Anemone	Star	-
11	3.9	3.9	Golden yellow	Semi-double	Star	Reflexed
12	5.5	5.3	Golden yellow	Single	Funnel	Flat, serrated
13	3.7	2.7	Golden orange	Semi-double	Bell	Frilled
14	5.7	5.7	Golden orange	Anemone	Star	-
15	5.6	1. 4	Golden yellow	Single	Tubular	Flat
16	4.0	0.5	Golden orange	Double	Tubular	Frilled, reflexed
17	3.8	3.8	Golden yellow	Anemone	Funnel	-
18	3.9	2.6	Golden orange	Semi-double	Transition	Reflexed
19	4.0	3.5	Light yellow-green	Single	Funnel	Frilled
20	4.0	3.5	Golden orange	Single	Funnel	Frilled
21	3.8	3.8	Reddish-orange	Anemone	Star	-
22	5.6	3.7	Golden yellow	Single	Tubular	Frilled
23	5.6	1.1	Bright yellow	Semi-double	Funnel	Flat
24	5.5	2.8	Golden orange	Semi-double	Tubular, funnel, star	Strap reflexed
25	5.5	5.5	Golden yellow	Single	Tubular	reflexed

genotypes play a significant role in the wide range of flower colors (Zhang et al., 2020). The broad colour spectrum enhances their marketability in floriculture, particularly for use in garlands, religious offerings, and decorative arrangements. Based on floral diameter, flowers were categorized into three size classes: small, medium, and large. Flowers with a diameter of less than 3.9 cm were classified as small, and small flowers were recorded in accessions 2, 3, 8, 10, 13, 17, and 21. Flowers with a medium size, measuring between 3.9 cm and 4.9 cm in diameter, were observed in accessions 16, 19, and 20. Flowers classified as large, with a diameter exceeding 5 cm, were recorded in accession numbers 1, 5, 6, 7, 9, 12, 14, 15, 22, 23, 24, and 25. *T. erecta* usually produces large double flowers measuring up to 12.7 cm in diameter. French marigolds have double and single flower varieties, but the double varieties are far more prevalent, featuring blooms that can reach up to 5cm in width. In contrast, Signet marigolds *(T. tenuifolia*) flowers feature a single row of petals and are about 2.5 cm-5 cm wide (Dalman, 2022). In a study conducted in West Bengal, India, the African marigold variety had outperformed the French and local cultivars in both flower diameter and the number of flowers produced per plant (Tiwary et al., 2014). However, In the present study, the widest flower diameter recorded was 5.8 cm. *T. erecta L.* and *T. patula L.* hold significant horticultural value and are cultivated commercially for their beautiful flowers (Ashritha et al., 2022).

According to ray and disc floret arrangements, the germplasm collection contained single, semi-double, double, and anemone-type flowers (Table 2).

Asteraceae is one of the largest families of flowering plants, distinguished by a distinctive head-like inflorescence consisting of a number of ray florets and disk florets. In this head-like structure, the outer florets are sterile ray florets that lack stamens, while the inner florets are fertile disk florets that contain all four whorl organs. Various morphological traits, including fertility, symmetry, and organ fusion, can be seen within a flower (Mandel et al., 2019). African marigolds are characterized by double rows of petals that may be notched or fringed; they present a textured and intricate look. This variation in petal formation creates a vibrant display of shapes and sizes (Grow Org, 2024).

In the present study, accessions 8, 9, 12, 15, 19, 20, and 22 contained a single whirl of ray florets. Usually, the single type of Marigold flower makes the disc florets highly visible and accessible. The appearance of a single-type marigold is similar to that of a daisy, with a distinct contrast between the outer ray florets and the inner disc florets. However, in this collection, the typical single-type marigold similar to the daisy flower was recorded by 2, 8, 15, and 22 accessions since the disc florets of the other accessions were crowded with a lot of ray florets. Functionally, this type is highly reproductive, as the disc florets remain fully functional in pollination and seed production. Because of their efficiency in natural reproduction, many wild marigold types exhibit this floral structure.

Semi-double types of flowers were recorded by accessions 1, 2, 3, 4, 11, 13, 18, 23, and 24. The disc florets are still partially visible in semi-double-type flowers, allowing for some reproductive functionality. The semi-double type balances ornamental value and pollination potential, making it a popular choice for decorative gardens and pollinator-friendly landscapes. While the increased number of ray florets enhances aesthetic appeal, it still allows partial access to the central reproductive structures. Many hybrid Marigold varieties fall into this category, bred for beauty and functional pollination.

According to floral characteristics, twenty-five Marigold accessions can be sorted using the following key.

1. Presence of ray florets in the flower
2. Ray florets are flat.
3.Disc floret tubes are tubular (2)
3'Disc floret tubes, not tubular
4. Has a semi-double flower type (23)
4'. Do not have a semi-double flower type
5. Disc floret diameter is less than 2 cm (15)
5'. Disc floret diameter not less than 2 cm (12)
2'. Ray florets are not flat. Mostly frilled.
6. Ray florets frilled:
7. Has a semi-double flower type
8. Ray florets are reflexed (4)
8'. Ray florets are not reflexed.
9. Dominant flower is colour yellow (3)
9'. Dominant flower is not colour yellow; orange yellow (1)

7'. Do not have a double flower type; single
10. Dominant flower colour is light yellow-green (19)
10'. The dominant flower colour is not light yellow-green
11. Ray Floret is reflexed (9)
11'. Ray floret is not reflexed (8)
6'. Ray florets are not frilled
12. Disc floret tube is bell-shaped (13)
12'. Disc floret tube is not bell-shaped
13. Presence of a double flower type
14. Disc floret is star shaped (11)
14'. Disc floret is not star shaped; Tubular (16)
13'. Do not have a double flower type
15. Disc floret type is transition (18)
15'. Disc floret type is not transition.
16. Have a semi-double flower type (24)
16'. Do not have a semi-double flower type
17. Disc floret is funnel-shaped (20)
17'. Disc floret is not funnel-shaped.
18. Ray Floret is reflexed (25)
18'. Ray floret is not reflexed (22)

Accession number 6 was a double type, and this type gives the flower a compact, fluffy, and spherical appearance, making it highly ornamental. Because the reproductive disc florets are hidden, these flowers are mostly sterile or have reduced pollination efficiency, requiring manual breeding techniques for propagation.

Accessions 5, 6, 7, 10, 14, 17, and 21 were anemone types. This creates a button-like or pom-pom appearance, with ray florets arranged around the prominent disc. Unlike double-type marigolds, anemone-type flowers retain some reproductive capability, as the large disc florets may contribute to seed production. This floral arrangement is less common and is usually seen in rare Marigold varieties, making them highly sought after for ornamental purposes.

Accessions 22 and 24 exhibited floral trimorphism, indicating mutations in disc floret development. Twenty-five accessions were characterized by plant height (cm), number of branches, side branches, and flowers per plant. The variation in accessions offers valuable information for their growth potential, structural robustness, and reproductive capacity, which are essential for selecting promising genotypes (Table 3).

Table 3: Plant morphology of the evaluated marigold accessions

Accession number	Height (cm)	NMB	NSB	NF
1	76	5	14	20
2	71	8	12	20
3	82	16	10	22
4	91	9	17	25
5	105	6	13	24
6	90	15	17	32
7	74	10	6	12
8	130	7	9	15
9	52	5	3	8
10	95	7	6	13
11	81	11	11	22
12	92	8	6	12
13	72	7	6	12
14	55	9	3	12
15	35	4	10	11
16	44	4	6	10
17	45	4	5	9
18	48	4	6	10
19	45	4	4	7
20	45	4	5	6
21	42	4	5	9
22	75	6	8	14
23	64	7	7	12
24	80	5	6	10
25	55	8	6	13

NMB: Number of main branches, NSB: Number of side branches, NF: Number of flowers

The plant height measurements demonstrated a wide range, from 35 cm in accession 15 to 130 cm in accession 8. This wide variation in plant height suggests that accessions might possess different genetic characteristics, while environmental factors could affect how plants grow. Plants with increased height tend to excel in resource acquisition, but shorter plants demonstrate better strength against lodging, ensuring suitability for specific farming practices. In a previous study by Venkatesh et al. (2023) on vegetative and flowering characters in *T. erecta*, different cultivars showed different heights; the 'Tennis Ball Plus' cultivar showed the highest plant height at 104.34 cm, followed by the 'Orange Glory' with a height of 93.03 cm. The 'Dimpal' cultivar had reached only 65.40 cm at 90 days after transplanting. These results show a notable variation in the height of different *T. erecta* cultivars, suggesting that some varieties have greater growth potential than others. This enhances the opportunities for selection and breeding programs to improve desirable traits of marigolds, such as height for commercial or ornamental purposes.

A wide range of primary branch numbers existed among accessions, which reached the highest count of 16 in accession 3, but reached the lowest count of 4 in accessions 15 to 21. Most accessions showed a growth habit with 4 to 10 branches, indicating neither a dense nor open shape. The side branch distributions between different accessions showed substantial variation because accessions 6 and 4 had 17 branches yet accessions 9 and 14 had only 3 branches. Plant branches tend to enhance flowering when they exceed a certain threshold in number.

In a previous study, the highest number of primary branches of *T. erecta* recorded was 13 at 90 days after transplanting. For secondary branches, the count was 40.55 (Venkatesh et al., 2023). Compared to these findings, some accessions showed even higher values, particularly accession 3, which had 16 primary branches, and accessions 6 and 4, which each had 17 secondary branches. Some accessions, like 9 and 14, only produced 3 secondary branches below the reported ranges, suggesting that branching patterns can vary significantly among different genetic backgrounds. Agronomic practices such as apical bud removal would be effective for this type of plant to increase the number of side branches for a higher number of flowers.

The number of flowers per plant expressed essential reproductive significance because it ranged between 6 flowers in accession 20 and 32 in accession 6. Most analyzed accessions produced 12 to 22 flowers each, indicating similar flowering patterns. The plant height was 90 cm, and the branching pattern was high in accession 6, combined with 9 main branches and 17 side branches, resulting in 32 flowers, while similar traits in accession 4 led to 9 branches with 17 side branches, yielding 25 flowers. The flower count showed a stronger relationship with the branching of the plants independently from plant height measurements. Selection programs should focus first on accessions which produce ample flowers because these will be the most promising candidates.

Furthermore, in a previous experiment by Venkatesh et al. (2023), the number of flowers produced per plant varies depending on several factors, including pinching type. The double pinched plants showed the highest number of flowers per plant, which was 90. This emphasizes that numerous factors can affect the number of flowers produced in a marigold plant, including the number of branches produced in a plant followed by pinching.

The observations showed no direct connection between plant height and flowering output because some tall accessions generated fewer flowers than shorter accessions. The measurement results showed accession 8, the tallest plant (130 cm), produced only 15 flowers despite its height, whereas accession 6 (90 cm) displayed 32 flowers as its highest number. The results showed that height cannot solely indicate successful reproduction. The flower count increased when plants displayed higher numbers of branches along with additional side branches. Accessions 6 and 4 demonstrated better agricultural output, including 15 branches, yet 17 side branches resulted in 32 flowers. The study indicates that reproductive potential depends on branching structure because multiple flowering sites enhance reproductive potential.

Plant height, branching patterns, and flower counts significantly affect the selection of better plants. The evaluation process would advance breeding programs by selecting accession numbers 6 and 4 because they show strong branching patterns with numerous flowers. Accessions with medium plant height and many flowers should be selected as priority breeding materials when compact growth and high yield are the main objectives. However, consumer preference would be colour and petal arrangement as well. The diversity of trait values in this accession collection demonstrated a significant genetic variability that researchers can use for agricultural improvement programs.

Principal Component Analysis

The eigenvalue analysis from the PCA revealed that three PCs scored more than 1 Eigen value and collectively describe 73.38% cumulative variances (Table 4). The first principal component (PC1) had an eigenvalue of 4.00 and accounted for 42.58% of the total variance, indicating its strong contribution to the overall differentiation among accessions. The second principal component (PC2) contributed an additional 18.17%, bringing the cumulative variance explained by the first two components to 60.75%. This suggests that a substantial portion of the morphological diversity among the flower accessions can be effectively captured in a two-dimensional PCA space. Subsequent components contributed progressively smaller proportions of the variance, supporting the focus on PC, PC2 and PC3 for visualizing and interpreting the main patterns of variation.

Table 4: Eigenvalues, proportion of variance, and cumulative variance explained by the principal components derived from the PCA of 25 flower accessions based on morphological traits

Principal Component	Eigenvalue	Variance (%)	Cumulative Variance (%)
PC1	4	42.58	42.58
PC2	1.71	18.17	60.75
PC3	1.19	12.63	73.38
PC4	0.85	9	82.39
PC5	0.76	8.06	90.45
PC6	0.44	4.7	95.14
PC7	0.29	3.09	98.23
PC8	0.15	1.56	99.79
PC9	0.02	0.21	100

PC: Principal component

The PCA loadings provided insight into the relative contribution of each morphological trait to the observed variability among flower accessions. Traits such as number of flowers, side branches, and dominant colour exhibited the highest positive loadings on the first principal component (PC1), which alone accounted for 42.58% of the total variation (Table 5). This suggests that these traits play a major role in differentiating accessions along the primary axis of variation. On the second principal component (PC2), which explained 18.17% of the variance, the most influential traits were disc floret diameter, complete flower diameter, and compendium shape. These findings highlight the importance of floral structure and branching characteristics in capturing the underlying phenotypic diversity. The direction and magnitude of the loadings further indicate how traits are correlated, with traits contributing similarly to a principal component being positively associated. The PCA loadings support the identification of key traits responsible for variability and provide a statistical basis for trait selection in breeding and diversity studies.

Table 5: Principal components (PCs) extracted from the ten traits studied in 25 Merigold accessions

	PC1	PC2	PC3	PC4	PC5	PC6	PC7
H	0.33	0	0.22	0.69	-0.31	0	-0.46
NMB	0.37	0.16	0.07	0.15	0.53	0.66	0.09
NSB	0.47	-0.1	-0.04	0.02	-0.15	-0.41	0.45
NF	**0.49**	0.05	0.01	0.1	0.1	-0.21	0.36
CFD	0.07	**0.58**	0.29	-0.29	-0.52	0.31	0.23
DFD	-0.02	**0.64**	0.26	-0.05	0.39	-0.5	-0.3
DC	-0.41	0.09	0.11	0.43	0.3	-0.06	0.48
CS	-0.25	0.39	-0.48	0.45	-0.26	0.05	0.17
DFT	-0.23	-0.2	0.74	0.14	-0.11	0	0.21

H: Height, NMB: Number of main branches, NSB: Number of side branches, NF: Number of flowers, CFD: Complete flower diameter, DFD: Disc florets diameter, DC: Dominant colour, CS: Compendium shape, DFT: Disc floret type

PCA biplot with trait loading

The PCA biplot revealed clear dispersion of accessions, suggesting substantial phenotypic diversity within the evaluated set (Figure 1). Trait loadings showed that number of flowers, side branches, and dominant colour contributed most strongly to PC1, while disc floret diameter, complete flower diameter, and compendium shape were the major contributors to PC2. These traits are therefore critical in distinguishing between accessions. Traits with vectors oriented in similar directions were positively correlated, while those in opposite directions were negatively associated. Overall, the PCA provided valuable insights into the structure of trait variation, supporting the identification of key phenotypic traits that drive differentiation among accessions.

Hierarchical cluster analysis using Ward's method and Euclidean distance successfully grouped the flower accessions based on their morphological traits. The resulting dendrogram revealed clear stratification, forming three major clusters, each representing groups of accessions with similar phenotypic profiles (Figure 2). This clustering supports the patterns observed in the PCA and reinforces the presence of substantial variability among the evaluated genotypes. Accessions within the same cluster shared common trait characteristics, while those in different clusters exhibited distinct morphological differences. Notably, traits such as number of flowers, branching pattern, and floral dimensions appeared to play a key role in defining the cluster boundaries. The observed clustering can aid in the selection of diverse parental lines for breeding programs, ensuring the exploitation of genetic variability and the development of improved cultivars with desirable traits.

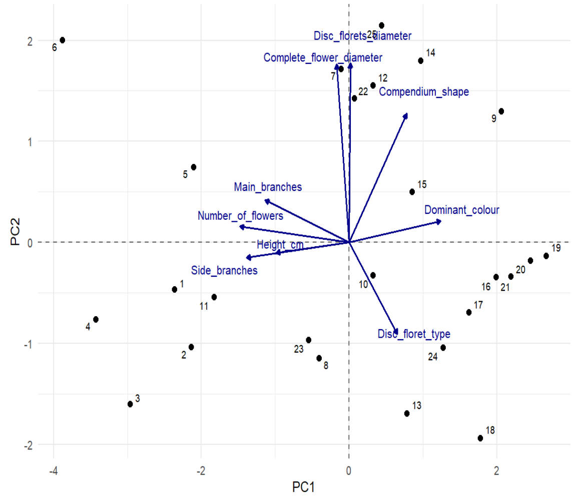

Figure 1. Principal Component Analysis (PCA) biplot of marigold accessions based on morphological traits.

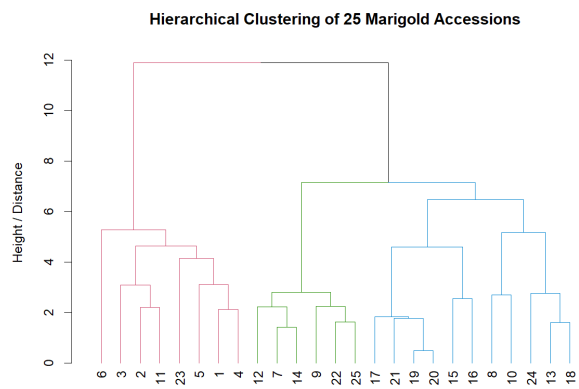

Figure 2. Hierarchical clustering dendrogram of 25 merigold accessions based on morphological traits, using Ward's method and Euclidean distance

Research has failed to document Sri Lankan marigold accessions throughout the past. The selection of commercially attractive flowers depends on the findings from this research, which determines flower attributes for business use according to their types, colours, and sizes. Further investigations need to be performed to enhance the number of accessions, which will support commercial breeding and population multiplication.

CONCLUSIONS

The study revealed significant variations in floral morphology among the evaluated twenty-five marigold accessions. The accessions displayed various flower colours, including yellow, orange, reddish-yellow, and golden hues. Based on floral diameter, flowers were classified into small (<3.9 cm), medium (3.9–4.9 cm), and large (>5 cm) categories. Floral forms varied in accessions, with single, semi-double, double, and anemone types. Single-type flowers, which maximize reproductive efficiency, were recorded in accessions 2, 8, 15, and 22, while semi-double types were noted in several accessions. Double and anemone-type flowers exhibited higher ornamental value. Interestingly, floral trimorphism was observed in accessions 22 and 24, highlighting unique floral diversity within Sri Lankan marigolds. The findings of this study have significant implications for the horticultural, commercial, and breeding potential of marigolds in Sri Lanka. The identified genetic variability could be utilized in breeding programs for ornamental varieties suited to urban landscaping and container gardening. The diversity in floral morphology, including single, semi-double, double, and anemone types, allows for targeted breeding based on ornamental preferences and reproductive efficiency. Single and semi-double types, with accessible disc florets, hold potential for pollinator-friendly landscaping, whereas double and anemone types are desirable for high-value ornamental displays. The discovery of floral trimorphism (accessions 22 and 24) presents opportunities for further genetic exploration and hybridization to develop novel marigold varieties with enhanced aesthetic and reproductive traits. Principal Component Analysis (PCA) effectively summarized the morphological variability among the flower accessions. Three principal components with eigenvalues greater than one were collectively explaining 73.38% of the total variance. Traits contributing most strongly to PC1 were number of flowers, number of main and side branches, indicating that floral productivity and branching habit are the primary sources of variation. On the other hand, disc floret diameter, complete flower diameter, and compendium shape were the major contributors to PC2, highlighting the importance of flower size and structure in phenotypic differentiation. These findings, as visualized in the PCA biplot, underscore the significance of both floral and vegetative traits in capturing genetic diversity among marigold accessions and suggest their utility as key descriptors for characterization and selection in breeding programs. Hierarchical clustering based on Ward's method grouped the accessions into three phenotypically distinct clusters, reinforcing the findings from PCA. These results underscore the presence of significant morphological diversity, which can be exploited for effective selection and breeding strategies.

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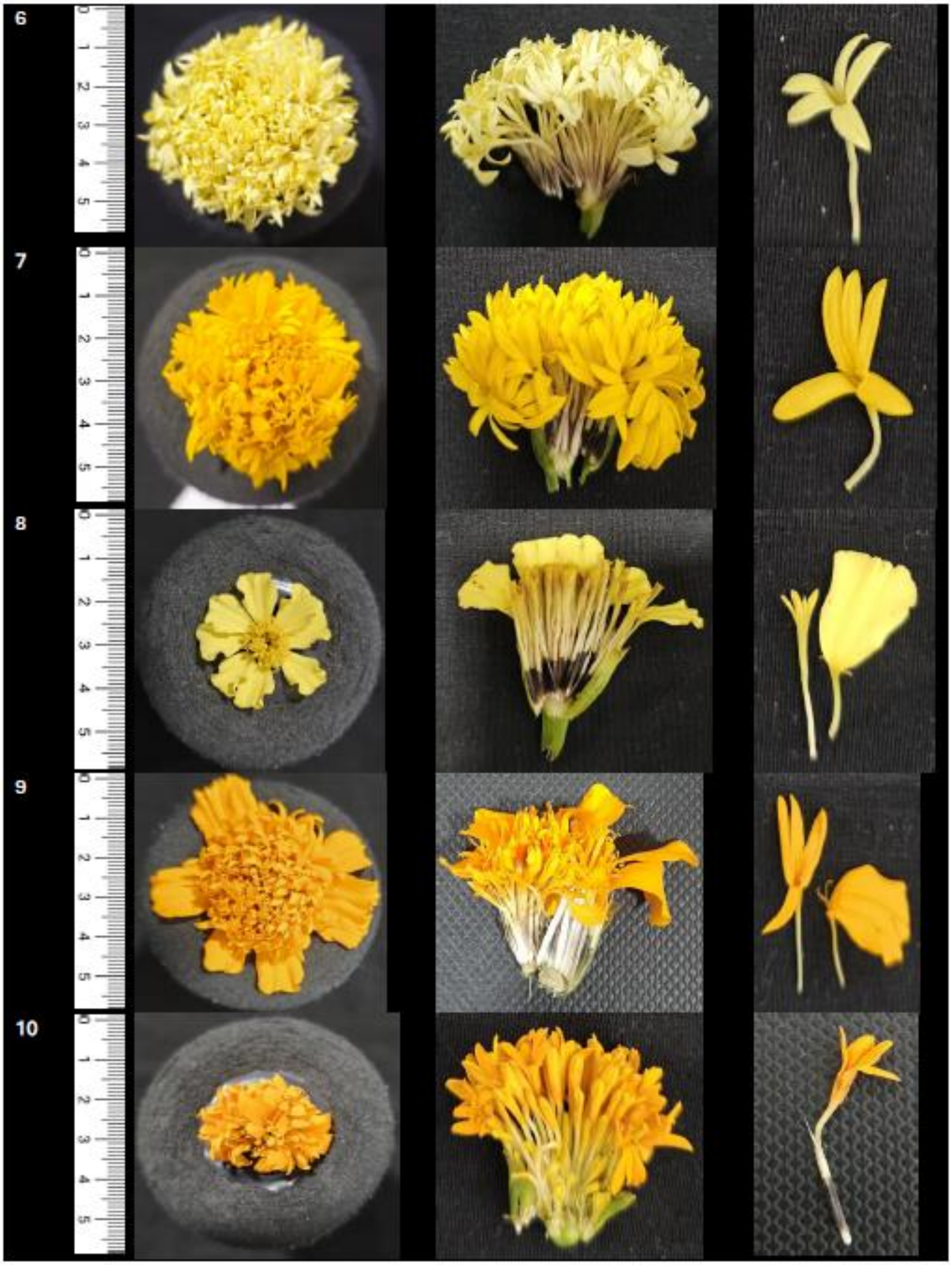
No
Scale (cm)
View from above
Cross sectional view
Ray or disc floret
1
2
3
4
5


6
7
8
9
10


11
12
13
3 cm
14
15


16
17
18
19
20

Supplementary Figure 1: Complete flower, cross section, disc floret and ray floret of Marigold accessions