



## Exploring genetic diversity and breeding potential in *Tagetes* species using morphological traits

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### ABSTRACT

Marigold is a commercially important flower crop valued for its ornamental and industrial uses. Genetic diversity among 137 genotypes was assessed using 17 morphological traits to identify diverse parents for crop improvement program. Significant diversity was observed in vegetative and reproductive traits between two *Tagetes* species. *Tagetes patula* genotypes were characterized by early flowering and higher number of flowers/plants, while *Tagetes erecta* genotypes exhibited larger flower diameter, higher flower weight and flower yield/plant. High heritability with high genetic advance over mean was recorded for most vegetative, flowering and seed traits, except flower diameter, suggesting scope of further improvement through selection. Principal component and Hierarchical cluster analyses grouped the genotypes into two major clusters that separated the species and identified genotypes with superior traits for targeted breeding programs.

**Key words:** Genetic diversity, heritability, multivariate analysis, morphological variability, PCA.

### INTRODUCTION

Marigold, a member of Asteraceae family, is a heliophile annual flower crop. Amongst the species, *Tagetes erecta* (African marigold) and *Tagetes patula* (French marigold) are two most widely cultivated species with somatic chromosomes of 24 and 48, respectively. Although, marigold is native to North America, they are extensively cultivated in Africa, Asia and Europe. In India, marigold is cultivated extensively, covering an area of 103.34 thousand hectares, with production of 1140.22 thousand metric tonnes (Anonymous, 1). Marigold is an ideal crop in multi-cropping systems due to its insecticidal, antimicrobial and phytoremediation properties (Fabrick *et al.*, 5; Madanan *et al.*, 6). French marigold is cultivated as a landscape plant due to its dwarf and compact growth habit with profuse flowering. On contrary, African marigold has double flowers in hues of orange and yellow with variable plant height and delayed flowering. Orange-coloured African marigold is also grown as an industrial cash crop for extraction of carotenoids, predominantly lutein which is used for treating age-related macular degeneration, atherosclerosis and cardiovascular diseases (Buscemi *et al.*, 2).

*Tagetes spp.* exhibits significant genetic variability as it is an often-cross-pollinated crop and both species are cross compatible. This variability provides ample opportunity for development of improved varieties with superior traits and broad genetic base. Understanding existing diversity within

germplasm for morphological traits can facilitate selection of diverse parents for future marigold improvement programmes. Therefore, the present study was conducted with an objective to determine degree of genetic diversity within marigold germplasm using morphological traits.

### MATERIALS AND METHODS

A total of 137 marigold genotypes comprising *T. erecta* (n=108) and *T. patula* (n=29), along with two standard checks *i.e.* Pusa Narangi Gaiinda and IIHRMO 12 were evaluated during November 2021 - March 2022. *T. erecta* genotypes were further classified based on flower morphology *viz.*, single, double, semi-double fertile, apetaloid and petaloid. The experiment was laid in an Augmented Randomized Block Design in 15 blocks. Standard checks were replicated in a Randomized Block Design in each block. Observations were recorded for plant height, number of primary and secondary branches/plant, plant spread, days to bud initiation, days to 50% flowering, flower diameter, calyx length, weight of ten flowers, weight of ray and disc florets, total number of flowers/plant, flower yield, number of seeds/capitulum, weight of 100 seeds and germination percentage. Recommended cultural package of practice was followed to raise a healthy crop (Tejaswini *et al.*, 10).

Descriptive statistics and genetic parameters were estimated across genotypes with the observed mean values of each genotype calculated from the original field data. Analysis of variance was carried out to determine significant differences

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among genotypes. Simple linear correlation, Principal Component Analysis and Two-way Hierarchical Cluster analysis using Ward's method was performed with observed mean values of each genotype using JMP10 Pro software.

## RESULTS AND DISCUSSION

Understanding extent of this diversity in germplasm is crucial step in breeding program as it reflects degree of trait differentiation within germplasm. In present study, 137 marigold genotypes were evaluated to identify the promising genotypes with superior traits. Significant phenotypic variations were observed for most of traits, indicating presence of substantial genetic diversity (Table 1). Among vegetative traits, maximum variation was recorded for number of secondary and primary branches/plant, while among flower traits, flower yield/plant recorded maximum variation. *T. patula* genotypes exhibited earlier bud initiation and took lesser number of days to 50% flowering compared to *T. erecta* genotypes which were late in bud initiation. *T. patula* genotypes also recorded higher total number of flowers/plant which ranged between 44.00 to 414.90 with a mean of 101.46 across the genotypes under study (Table 2). *T. erecta* genotypes recorded wider variation for flower diameter ranging between 3.36 - 5.96cm and weight of ten flowers that ranged between 9.90 - 53.99g. Cicevan *et al.* (3) reported similar differences, *T. patula* genotypes recorded shorter plant height, lesser number of branches and higher number of flowers/plant and *T. erecta* genotypes recorded higher plant height. This rich diversity within germplasm underscores their potential to significantly contribute to breeding programs by harnessing these traits for enhancing the genetic pool. Zhang *et al.* (13) reported successful interspecific hybridization between African and French marigold that resulted in hybrids with super-parental traits.

Classification of *T. erecta* genotypes into distinct flower forms provides a critical understanding about variations in floral architecture (Dedhia *et al.*, 4). This grouping of genotypes also suggested that flower forms are significant determinant of agronomic performance, with each type exhibiting superior trait variations. Significant phenotypic variation was recorded in different flower forms of *T. erecta* for all traits (Table 2). Among vegetative traits, highest variation was observed for number of primary and secondary branches/plant in double fertile genotypes. Similarly, among flower traits, wider variation was observed in apetaloid genotypes for total number of flowers/plant and flower yield/plant followed by single fertile genotypes. Wider morphological variations

**Table 1:** Analysis of variance for morphological traits of marigold genotypes evaluated in augmented block design.

| Source of variation             | df  | PH        | PB      | SB       | PS       | DI       | 50 F      | DIA     | CL      | WTF       | WRF     | WDF     | TNF        | YPP    | SL      | SC          | SW         | GP         |
|---------------------------------|-----|-----------|---------|----------|----------|----------|-----------|---------|---------|-----------|---------|---------|------------|--------|---------|-------------|------------|------------|
| Treatments (ignoring blocks)    | 136 | 134.76**  | 9.03**  | 123.17** | 79.95**  | 63.85**  | 78.01**   | 0.452ns | 0.058** | 95.18**   | 0.79**  | 0.314** | 3950.86**  | 0.01*  | 0.45**  | 8533.10**   | 3859.01**  | 894.89**   |
| Checks                          | 1   | 1720.66** | 48.74** | 27.82ns  | 5.17 ns  | 879.13** | 1254.53** | 0.55 ns | 1.85**  | 1010.01** | 15.78** | 1.97**  | 3206.43**  | 0.01ns | 5.44**  | 71538.88**  | 2637.28**  | 48.13 ns   |
| Test entries                    | 134 | 122.01**  | 8.35**  | 117.92** | 79.96**  | 53.11**  | 66.52**   | 0.45 ns | 0.045** | 81.33*    | 0.68**  | 0.304** | 3826.87**  | 0.01*  | 0.35**  | 4389.40**   | 3717.83**  | 647.80**   |
| Test entries vs. Checks         | 1   | 256.45**  | 60.35** | 922.13** | 152.50** | 688.00** | 441.58**  | 0.80 ns | 0.00 ns | 1035.29** | 1.42**  | 0.001ns | 21310.24** | 0.00ns | 8.21**  | 500783.54** | 23999.84** | 34851.95** |
| Blocks (eliminating treatments) | 14  | 18.84ns   | 1.81ns  | 18.52ns  | 14.69ns  | 14.67ns  | 9.96ns    | 0.13ns  | 0.00ns  | 22.01ns   | 0.01ns  | 0.02 ns | 437.96ns   | 0.00ns | 0.004ns | 595.86 ns   | 317.70 ns  | 598.53**   |
| Error                           | 14  | 18.37     | 2.18    | 24.83    | 12.95    | 11.63    | 10.82     | 0.23    | 0.00    | 30.27     | 0.02    | 0.01    | 351.58     | 0.00   | 0.01    | 558.08      | 195.61     | 48.13      |
| CV (%)                          |     | 10.03     | 12.94   | 14.18    | 9.48     | 6.54     | 5.17      | 11.10   | 2.28    | 24.45     | 20.33   | 12.22   | 17.60      | 29.67  | 4.60    | 14.71       | 7.69       | 19.66      |

\*\* Significant at 1% level; \* significant at 5% level; ns: non-significant.

PH= Plant height (cm); PS= Plant spread (cm<sup>2</sup>); PB= Number of primary branches /plant; SB= Number of secondary branches /plant; DI= Days to bud initiation; 50F= Days required to 50% flowering; DIA= Flower Diameter (cm); CL= Calyx length (cm); WTF= Weight of ten flowers (g); WRF= Weight of ray florets (g); WDF= Weight of disc florets (g); TNF= Total number of flowers /plant; YPP= Flower yield /plant; (kg); SL= Shelf life (days); SC=Number of seeds /capitulum; SW= Weight of 100 seeds (mg); GP= Germination Percentage

**Table 2:** Descriptive statistics of *Tagetes patula* and *Tagetes erecta* genotypes, including flower forms of *T. erecta*, for morphological traits.

| Trait                              | <i>T. patula</i><br>(n = 29)      | <i>T. erecta</i> (n = 108)       |                                   |                                   |                                  |                                  |                                   |                                   |
|------------------------------------|-----------------------------------|----------------------------------|-----------------------------------|-----------------------------------|----------------------------------|----------------------------------|-----------------------------------|-----------------------------------|
|                                    |                                   | <i>T. erecta</i><br>Overall      | Male sterile lines                |                                   |                                  | Fertile lines                    |                                   |                                   |
|                                    |                                   |                                  | Petaloid<br>(Genic)               | Apetaloid<br>(Genic)              | Petaloid<br>(Cytoplasmic)        | Single                           | Semi-double                       | Double                            |
| Plant height (cm)                  | 34.20 ± 15.04<br>(18.40-92.60)    | 45.72 ± 8.16<br>(29.60-74.60)    | 50.52 ± 4.00<br>(42.80-55.67)     | 43.34 ± 7.57<br>(31.80-58.00)     | 53.87 ± 4.50<br>(49.40-58.40)    | 45.14 ± 9.21<br>(29.60-74.60)    | 45.14 ± 4.60<br>(34.60-52.40)     | 48.36 ± 6.04<br>(40.40-61.00)     |
| Number of primary branches/plant   | 10.37 ± 3.65<br>(5.80-23.33)      | 12.02 ± 2.54<br>(4.67-19.67)     | 12.38 ± 1.74<br>(8.67-14.00)      | 10.66 ± 2.18<br>(8.00-15.00)      | 13.08 ± 2.51<br>(10.33-15.25)    | 12.33 ± 2.65<br>(4.67-19.67)     | 11.27 ± 1.81<br>(8.33-13.67)      | 12.17 ± 2.85<br>(7.20-16.20)      |
| Number of secondary branches/plant | 29.47 ± 11.29<br>(14.80-70.00)    | 37.95 ± 9.98<br>(14.67-62.00)    | 43.95 ± 7.43<br>(33.33-54.67)     | 33.82 ± 8.52<br>(25.00-56.00)     | 49.69 ± 10.14<br>(41.40-61.00)   | 37.13 ± 9.88<br>(14.67-60.67)    | 40.57 ± 8.67<br>(27.20-56.75)     | 38.58 ± 11.40<br>(20.40-62.00)    |
| Plant spread (cm)                  | 34.93 ± 13.29<br>(22.50-91.67)    | 39.28 ± 7.07<br>(19.50-54.46)    | 44.94 ± 4.97<br>(39.63-51.17)     | 35.04 ± 7.94<br>(19.50-45.90)     | 47.55 ± 1.10<br>(46.34-48.50)    | 38.59 ± 7.03<br>(21.10-52.30)    | 40.21 ± 6.07<br>(26.33-50.30)     | 41.92 ± 6.63<br>(30.50-54.46)     |
| Days to bud initiation             | 44.34 ± 6.47<br>(33.00-65.40)     | 53.07 ± 6.35<br>(31.27-68.00)    | 53.37 ± 6.66<br>(47.40-62.67)     | 52.56 ± 6.07<br>(43.60-61.60)     | 43.36 ± 10.79<br>(31.27-52.00)   | 54.40 ± 5.81<br>(44.40-68.00)    | 52.05 ± 4.13<br>(45.80-60.20)     | 51.22 ± 8.38<br>(31.60-67.80)     |
| Days to 50% flowering              | 53.76 ± 6.86<br>(46.00-68.00)     | 65.42 ± 6.56<br>(50.40-78.00)    | 68.71 ± 11.29<br>(55.00-83.00)    | 67.10 ± 7.22<br>(55.00-78.00)     | 62.80 ± 11.46<br>(50.40-73.00)   | 66.69 ± 6.24<br>(51.00-78.00)    | 62.77 ± 5.61<br>(57.00-75.00)     | 62.74 ± 6.45<br>(57.00-76.00)     |
| Flower diameter (cm)               | 3.63 ± 0.82<br>(2.46-5.69)        | 4.46 ± 0.49<br>(3.36-5.96)       | 4.86 ± 0.32<br>(4.44-5.25)        | 4.38 ± 0.43<br>(3.61-4.99)        | 4.75 ± 0.49<br>(4.28-5.25)       | 4.43 ± 0.48<br>(3.36-5.96)       | 4.31 ± 0.44<br>(3.69-5.10)        | 4.70 ± 0.62<br>(3.83-5.62)        |
| Calyx length (cm)                  | 2.06 ± 0.30<br>(1.71-3.02)        | 1.94 ± 0.18<br>(1.56-2.53)       | 1.99 ± 0.20<br>(1.79-2.23)        | 2.00 ± 0.16<br>(1.74-2.23)        | 1.87 ± 0.06<br>(1.80-1.92)       | 1.94 ± 0.20<br>(1.56-2.53)       | 1.91 ± 0.13<br>(1.73-2.19)        | 1.95 ± 0.11<br>(1.83-2.21)        |
| Weight of ten flowers (g)          | 17.68 ± 12.60<br>(7.48-50.15)     | 22.41 ± 7.54<br>(9.90-53.99)     | 32.16 ± 9.00<br>(18.98-42.81)     | 22.32 ± 5.79<br>(11.07-30.27)     | 29.06 ± 8.91<br>(19.08-36.20)    | 20.58 ± 6.95<br>(9.90-53.99)     | 22.44 ± 6.96<br>(14.08-37.26)     | 28.39 ± 7.81<br>(16.92-42.91)     |
| Weight of ray florets (g)          | 0.77 ± 0.75<br>(0.18-3.25)        | 0.70 ± 0.84<br>(0.04-4.23)       | 2.08 ± 2.22<br>(0.25-5.26)        | 0.82 ± 1.10<br>(0.18-3.53)        | 2.61 ± 1.40<br>(1.67-4.23)       | 0.43 ± 0.63<br>(0.04-3.85)       | 0.86 ± 0.59<br>(0.29-2.11)        | 1.48 ± 0.78<br>(0.48-2.96)        |
| Weight of disc florets (g)         | 0.79 ± 0.91<br>(0.27-5.25)        | 0.91 ± 0.40<br>(0.00-3.01)       | 0.39 ± 0.44<br>(0.00-1.07)        | 1.12 ± 0.39<br>(0.28-1.76)        | 0.00 ± 0.00<br>(0.00-0.00)       | 0.93 ± 0.31<br>(0.32-2.13)       | 0.98 ± 0.26<br>(0.62-1.36)        | 0.85 ± 0.67<br>(0.21-3.01)        |
| Total number of flowers/plant      | 148.74 ± 79.28<br>(44.10-414.90)  | 101.46 ± 51.85<br>(22.00-278.40) | 87.23 ± 23.82<br>(45.34-115.25)   | 70.91 ± 39.42<br>(29.50-155.38)   | 123.50 ± 60.67<br>(53.48-160.33) | 102.60 ± 55.16<br>(23.53-278.40) | 117.14 ± 52.22<br>(22.00-190.75)  | 99.96 ± 44.83<br>(31.97-187.45)   |
| Flower yield/plant (kg)            | 0.22 ± 0.11<br>(0.08-0.53)        | 0.21 ± 0.11<br>(0.03-0.58)       | 0.28 ± 0.10<br>(0.16-0.47)        | 0.17 ± 0.12<br>(0.03-0.44)        | 0.39 ± 0.26<br>(0.10-0.58)       | 0.19 ± 0.08<br>(0.08-0.38)       | 0.24 ± 0.08<br>(0.08-0.38)        | 0.28 ± 0.15<br>(0.09-0.57)        |
| Shelf life (days)                  | 1.72 ± 0.73<br>(0.93-3.03)        | 1.75 ± 0.56<br>(0.64-3.03)       | 2.16 ± 0.49<br>(1.64-2.76)        | 1.89 ± 0.58<br>(1.00-2.78)        | 2.26 ± 0.36<br>(2.06-2.68)       | 1.62 ± 0.59<br>(0.64-3.03)       | 1.66 ± 0.40<br>(0.78-2.10)        | 2.15 ± 0.30<br>(1.93-2.76)        |
| Number of seeds/capitulum          | 81.87 ± 58.51<br>(11.67-251.33)   | 151.51 ± 63.13<br>(0.00-346.00)  | 155.19 ± 49.65<br>(93.67-224.33)  | 141.60 ± 50.72<br>(55.67-210.00)  | -                                | 162.99 ± 65.48<br>(27.00-346.00) | 127.03 ± 36.37<br>(50.67-175.33)  | 157.23 ± 41.14<br>(70.33-228.69)  |
| Weight of 100 seeds (mg)           | 175.37 ± 42.69<br>(110.60-296.30) | 190.25 ± 64.43<br>(0.00-318.90)  | 169.99 ± 60.78<br>(100.00-250.50) | 221.38 ± 48.46<br>(142.30-286.60) | -                                | 188.57 ± 58.25<br>(77.20-318.90) | 208.62 ± 42.38<br>(120.80-269.70) | 198.07 ± 65.22<br>(100.00-285.80) |
| Germination percentage (%)         | 32.31 ± 24.80<br>(2.00-82.00)     | 42.90 ± 25.28<br>(0.00-89.00)    | 41.00 ± 13.24<br>(27.00-61.00)    | 38.40 ± 23.61<br>(3.00-74.00)     | -                                | 47.58 ± 24.59<br>(3.00-89.00)    | 42.69 ± 24.73<br>(1.00-81.00)     | 36.69 ± 27.50<br>(0.00-86.00)     |

Values are Mean ± SD with range (Min-Max) in parentheses. -: not applicable; cytoplasmic male sterile line does not set seed. n= number of genotypes

observed among different forms of fertile and sterile genotypes suggests suggested their selection as pollen and seed parents, respectively for future heterosis breeding.

Genetic parameters were estimated for all traits across genotypes (Table 3). Higher GCV and heritability values were observed for plant height, plant spread and number of branches, depicting substantial genetic variability with moderate environmental influence. Among reproductive traits, days to bud initiation, days to 50% flowering and flower diameter recorded moderate GCV, suggesting preponderance of non-additive gene action where selection would be less effective owing to substantial influence of environment on their expression. Thus, base population can be further enhanced through hybridization followed by selection. Higher heritability and moderate to low GAM for flower diameter indicated possible involvement of non-additive genetic effects and environmental influence on trait expression. Rymbai *et al.* (8) also showed similar results for flower diameter, vase life, number of flowers and days to bud burst in gerbera. Total number of flowers/plant, weight of ray and disc florets, flower yield/plant, number of seeds/capitulum and weight of 100 seeds recorded high GCV and heritability with higher GAM. High broad-sense heritability coupled

with high genetic advance indicates that these traits may respond to selection, although confirmation of additive genetic control would require further genetic analysis.

Simple linear correlation analyses revealed that majority of vegetative characters were positively correlated with each other (Table 4). Flower yield/plant was significant and positively correlated with all vegetative traits and total number of flowers/plant ( $r = 0.653$ ), suggesting that selection for these traits could enhance yield. This association suggested agronomy practices will improve plant architecture which can indirectly increase flower yield (Yan *et al.*, 12). Moreover, these traits were also significantly correlated with each other, suggesting simultaneous improvement of these traits (Savadi *et al.*, 9). Poulouse *et al.* (7) and Thakur and Kaur (11) also reported significant positive correlation between flower yield, number of branches, flower weight and number of flowers/plant in marigold. Weight of ten flowers was positively correlated with plant height and days to 50% flowering but negatively correlated with total number of flowers/plant ( $r = -0.424$ ). Flower diameter was positively correlated with days to bud initiation, days to 50% flowering and weight of ten flowers but negatively correlated with total number of flowers/plant ( $r = -0.444$ ). This inverse association helps

**Table 3:** Genetic parameters for different morphological traits observed in marigold genotypes.

| Traits                             | Mean   | GCV    | PCV    | $h^2b$ | GAM    |
|------------------------------------|--------|--------|--------|--------|--------|
| Plant height (cm)                  | 43.28  | 23.52  | 25.52  | 84.95  | 44.73  |
| Plant spread (cm <sup>2</sup> )    | 38.36  | 21.34  | 23.31  | 83.80  | 40.30  |
| Number of primary branches/plant   | 11.67  | 21.28  | 24.75  | 73.89  | 37.73  |
| Number of secondary branches/plant | 36.16  | 26.68  | 30.03  | 78.95  | 48.91  |
| Days to bud initiation             | 51.22  | 12.57  | 14.23  | 78.11  | 22.93  |
| Days to 50 percent flowering       | 62.95  | 11.86  | 12.96  | 83.74  | 22.38  |
| Flower diameter (cm)               | 4.29   | 10.91  | 15.63  | 48.79  | 15.73  |
| Calyx length (cm)                  | 1.97   | 10.55  | 10.80  | 95.57  | 21.28  |
| Weight of ten flower (g)           | 21.40  | 33.37  | 42.11  | 62.78  | 54.55  |
| Weight of ray florets (g)          | 0.72   | 113.04 | 115.06 | 96.52  | 229.10 |
| Weight of disc florets (g)         | 0.89   | 60.88  | 62.09  | 96.14  | 123.16 |
| Total Number of flowers/plant      | 111.47 | 52.89  | 55.50  | 90.81  | 103.98 |
| Flower yield/plant (kg)            | 0.22   | 41.41  | 51.03  | 65.83  | 69.31  |
| Shelf life (days)                  | 1.74   | 33.69  | 34.04  | 97.97  | 68.79  |
| Number of seeds/capitulum          | 136.84 | 45.23  | 48.42  | 87.29  | 87.18  |
| Weight of 100 seeds (mg)           | 187.13 | 31.72  | 32.58  | 94.74  | 63.68  |
| Germination percentage             | 43.82  | 55.88  | 58.08  | 92.57  | 110.92 |

GCV- Genotypic Coefficient of Variation, PCV- Phenotypic Coefficient of Variation,  $h^2b$ - Heritability (%; broad sense), GAM- Genetic Advance over Mean

**Table 4:** Simple linear correlation matrix for morphological traits in marigold genotypes.

|     | PB       | SB       | PS       | DI       | 50 F     | DIA      | CL        | WTF      | WRF      | WDF      | TNF       | YPP      | SL       | SC        | SW       | GP       |
|-----|----------|----------|----------|----------|----------|----------|-----------|----------|----------|----------|-----------|----------|----------|-----------|----------|----------|
| PH  | 0.671*** | 0.580*** | 0.717*** | 0.454*** | 0.421*** | 0.516*** | 0.092     | 0.329*** | 0.222**  | -0.031   | 0.131     | 0.490*** | 0.208*   | 0.189*    | -0.028   | -0.007   |
| PB  |          | 0.713*** | 0.578*** | 0.510*** | 0.362*** | 0.368*** | 0.042     | 0.113    | 0.031    | -0.006   | 0.280***  | 0.486*** | 0.154    | 0.291***  | -0.169*  | -0.059   |
| SB  |          |          | 0.644*** | 0.435*** | 0.386*** | 0.169*   | -0.157    | -0.012   | -0.007   | -0.135   | 0.417***  | 0.556*** | 0.205*   | 0.138     | -0.231** | -0.088   |
| PS  |          |          |          | 0.305*** | 0.280*** | 0.221**  | -0.033    | 0.077    | 0.118    | -0.142   | 0.399***  | 0.589*** | 0.110    | 0.079     | -0.111   | -0.074   |
| DI  |          |          |          |          | 0.818*** | 0.452*** | -0.244**  | 0.205*   | -0.051   | 0.106    | -0.100    | 0.134    | 0.160    | 0.491***  | -0.023   | 0.165    |
| 50F |          |          |          |          |          | 0.447*** | -0.366*** | 0.282*** | 0.045    | 0.028    | -0.202*   | 0.079    | 0.130    | 0.494***  | -0.042   | 0.242**  |
| DIA |          |          |          |          |          |          | 0.143     | 0.739*** | 0.423*** | 0.288*** | -0.444*** | 0.178*   | 0.327*** | 0.481***  | 0.031    | 0.027    |
| CL  |          |          |          |          |          |          |           | 0.258**  | 0.230**  | 0.123    | 0.052     | 0.131    | 0.193*   | -0.026    | 0.224**  | -0.056   |
| WTF |          |          |          |          |          |          |           |          | 0.634*** | 0.344*** | -0.424*** | 0.293*** | 0.435*** | 0.322***  | 0.077    | -0.005   |
| WRF |          |          |          |          |          |          |           |          |          | -0.121   | -0.152    | 0.294*** | 0.376*** | -0.057    | -0.179*  | -0.084   |
| WDF |          |          |          |          |          |          |           |          |          |          | -0.297*** | -0.065   | 0.062    | 0.354***  | 0.333*** | -0.019   |
| TNF |          |          |          |          |          |          |           |          |          |          |           | 0.653*** | -0.084   | -0.301*** | -0.171*  | -0.180*  |
| YPP |          |          |          |          |          |          |           |          |          |          |           |          | 0.243**  | -0.062    | -0.194*  | -0.27**  |
| SL  |          |          |          |          |          |          |           |          |          |          |           |          |          | 0.061     | -0.101   | -0.168*  |
| SC  |          |          |          |          |          |          |           |          |          |          |           |          |          |           | 0.183*   | 0.270**  |
| SW  |          |          |          |          |          |          |           |          |          |          |           |          |          |           |          | 0.432*** |

\*\*\*Correlation is significant at 0.001 level (two tailed); \*\* Correlation is significant at 0.01 level (two tailed); \* Correlation is significant at 0.05 level (two tailed)  
 Note: Abbreviations as in Table 1

breeder in prioritizing the selection of genotypes based on the targeted-end-use. For instance, genotypes with higher flower number are best for loose-market production, where flower volume is primary objective. Conversely, genotypes with higher flower weight and diameter which will be superior candidate for the industrial applications. 100-seed weight was positively correlated with weight of disc floret, indicating improved floral development will improve seed quality.

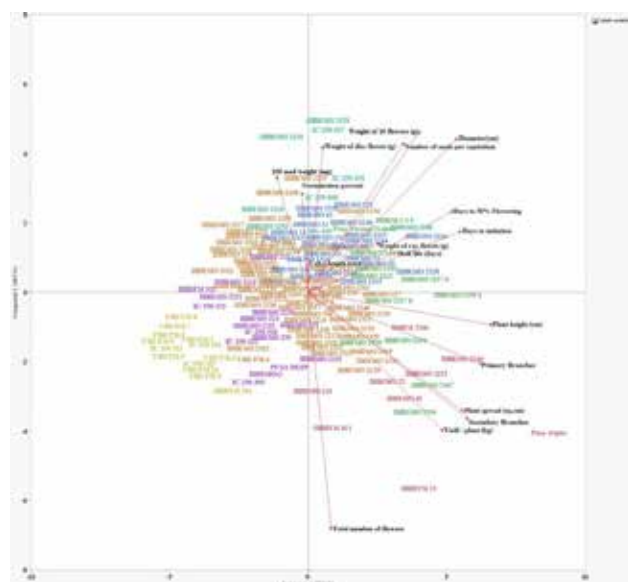
Principal Component analysis was carried out for all the traits to understand their intricate relationship. First five principal components (PCs) with eigenvalues (>1) accounted for 75.17% of total variability (Table 5). PC1 explained 27.83% of variability, with vegetative traits contributing 48% and reproductive traits such as days to bud initiation, days to 50% flowering, weight of ten flowers, flower diameter and yield/plant contributing 41%. PC2 and PC3, accounted for 18.5% and 13.72% of variability, respectively. PC2 was influenced by total number of flowers/plant, weight of ten flowers, flower yield/plant, flower diameter and weight of disc florets. Further, in PC3, weight of ray florets, calyx length and days to 50% flowering were maximum contributors. Yan *et al.* (12) similarly reported maximum phenotypic variation in 89 marigold accessions was due to plant growth and flowering traits in first and second principal components, respectively. PCA biplot showed that in first quadrant, vegetative traits and yield/plant contributed significantly to variability. In second quadrant traits *viz.*, flower diameter, weight of ten flowers, days to initiation, days to 50% flowering, number of seeds/capitulum, weight of disc florets and shelf life contributed significantly (Fig. 1). Further, angle and length of vectors corresponding to each trait in different components explain the variability. For instance, number of secondary branches/plant, plants spread, number of primary branches/plant contributed the most in PC1, formed an acute angle with each other. Flower yield/ plant also formed an acute angle with plant spread, number of secondary branches, indicating their strength for maximum exploitation in future trait-specific breeding.

Hierarchical cluster analysis using Ward's method divided the genotypes into two major clusters (Figure 2) separating both *Tagetes* spp. Such trait-specific grouping aids in selection and utilization of genotypes for targeted breeding objectives (Yan *et al.*, 12). Sub-cluster I-a included genotypes with superior vegetative growth but exhibited delayed flowering. Sub-cluster I-b, consisted genotypes with higher flower yield. Sub-clusters I-c, I-d and I-e

**Table 5:** Eigen values and loading values for morphological traits observed through principal component analysis.

| Principal components               | PC1   | PC2   | PC3   | PC4   | PC5   |
|------------------------------------|-------|-------|-------|-------|-------|
| Eigen value                        | 4.73  | 3.15  | 2.33  | 1.48  | 1.09  |
| Percentage of variance             | 27.83 | 18.50 | 13.72 | 8.70  | 6.42  |
| Cumulative percentage of variance  | 27.83 | 46.33 | 60.05 | 68.75 | 75.17 |
| Loading values                     |       |       |       |       |       |
| Plant height (cm)                  | 0.83  | -0.12 | 0.03  | 0.17  | 0.16  |
| Plant spread (cm <sup>2</sup> )    | 0.72  | -0.46 | -0.20 | 0.03  | -0.07 |
| Number of primary branches/plant   | 0.78  | -0.26 | -0.15 | 0.16  | -0.13 |
| Number of secondary branches/plant | 0.70  | -0.43 | -0.04 | 0.18  | 0.14  |
| Days to bud initiation             | 0.69  | 0.22  | -0.49 | -0.15 | -0.07 |
| Days to 50 percent flowering       | 0.65  | 0.30  | -0.49 | -0.30 | 0.10  |
| Flower Diameter (cm)               | 0.68  | 0.56  | 0.22  | -0.07 | -0.03 |
| Calyx length                       | -0.01 | 0.11  | 0.60  | 0.56  | 0.06  |
| Weight of ten flowers (g)          | 0.51  | 0.58  | 0.53  | -0.05 | 0.04  |
| Weight of ray florets (g)          | 0.32  | 0.18  | 0.69  | -0.28 | 0.39  |
| Weight of disc florets (g)         | 0.07  | 0.53  | 0.04  | 0.39  | -0.62 |
| Total number of flowers/plant      | 0.11  | -0.86 | 0.01  | 0.29  | -0.01 |
| Flower yield/plant (kg)            | 0.61  | -0.50 | 0.35  | 0.19  | -0.05 |
| Shelf life (days)                  | 0.40  | 0.15  | 0.47  | -0.18 | -0.08 |
| Number of seeds/ capitulum         | 0.44  | 0.54  | -0.35 | 0.15  | -0.18 |
| Weight of 100 seeds (mg)           | -0.15 | 0.42  | -0.15 | 0.72  | 0.21  |
| Germination percentage             | -0.03 | 0.36  | -0.44 | 0.29  | 0.64  |

exhibited variations in vegetative and reproductive traits, with genotypes in I-d characterized by taller

**Fig. 1.** Principal component biplot analysis for 17 morphological traits in marigold genotypes.

plants and higher number of seeds/capitulum and I-e was characterized by superior flower traits like weight of ten flower and diameter. Cluster II was subdivided into II-a and II-b. Sub-cluster II-a predominantly included *T. erecta* genotypes, while II-b included *T. patula* genotypes early to flowering marigold genotypes with more number of flowers/plant. Genotypes of these clusters being highly distinct are ideal for selection as seed and pollen parents for future breeding programs aimed at broadening genetic base of marigold (Ciecevan *et al.*, 3; Rymbai *et al.*, 8; Yan *et al.*, 12).

The results from study inferred significant genetic variation among *Tagetes* spp. genotypes for all morphological traits under study. The observed phenotypic distinction between species offers scope for selecting parents for intra- and interspecific hybridization to develop heterotic combinations and cultivars with improved ornamental value. However, further evaluation across diverse environments and locations is required which would contribute to a better understanding about the stability and adaptability of these genotypes for their effective utilization in breeding programmes.

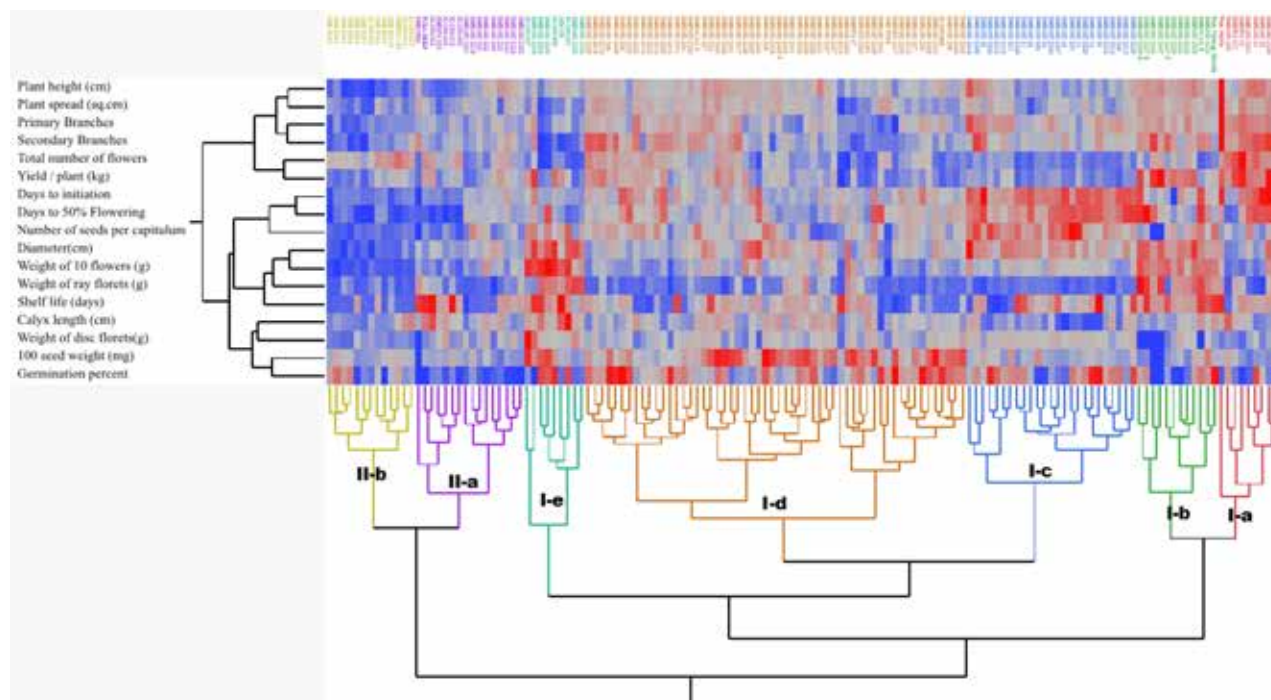


**Fig. 2.** Grouping of marigold genotypes using two-way hierarchical cluster analysis based on morphological traits.

## AUTHOR'S CONTRIBUTION

Data curation, Formal analysis, Software, Visualization, Writing - original draft (LD); Conceptualization, Methodology, Resource, Writing-review & editing (TP); Methodology, Software, Writing-review & editing (AM); Formal analysis, Software (VR).

## DECLARATIONS

The authors hereby declare that they have no conflict of interest.

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