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Multivariate analysis of genetic diversity and lutein yield-related traits in African marigold (Tagetes erecta L.) genotypes

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Multivariate analysis of genetic diversity and lutein yield-related traits in African marigold (*Tagetes erecta* L.) genotypes

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Abstract

Background The lutein compound is widely recognized for its high medicinal and potent antioxidant value. Enhancing economic returns and meeting the rising demand for lutein necessitate quantifying lutein concentration and total lutein yield from *Tagetes erecta* flowers across genotypes and their exploitation in lutein rich cultivar improvement. However, systematic evaluation of its genetic resources remains limited. Therefore, the present study aimed to assess 29 twenty-nine African marigold genotypes for genetic variability, trait associations, and genetic diversity through multivariate technique to identify suitable genotypes for lutein content and yield.

Results The nature and amount of variability and correlations were examined in the twenty-three traits of twenty-nine collections of African marigold genotypes. The genotypes, *viz.,* M-4, M-5, M-7, M-8, M-9, M-10, M-14, M-15, M-16, M-23, M-24, M-26, M-27, and M-29, have high lutein content and yield, and were significantly exploited in the lutein-rich varietal improvement programme. High heritability and genetic advancement for key traits like oleoresin content (99.85%; 52.91 %), lutein content (99.80%; 64.69 %), and lutein yield (86.11%; 80.91 %) highlighted the breeding/genetic improvement potential. Correlation and path coefficient revealed that, lutein yield (r = 1.00) had a strong direct positive association with lutein content (r = 0.73 **), dry yield of petals (r = 0.69 **), fresh yield of petals (r = 0.69 **), flower yield per hectare (r = 0.69 **), flower yield per plot (r = 0.69 **), flower yield per plant (r = 0.69 **), oleoresin yield (r = 0.69 **), fresh weight of flower (r = 0.65 **), number of petals per flower (r = 0.60 **). The screened genotype M-10, which is significantly diverse among the other cluster genotypes, provided a wider scope for isolating desirable parents for breeding lutein rich varieties/hybrid.

Conclusions The results provide a strong basis for selection and hybridization programs in African marigold. Lutein content and lutein yield should be prioritized as selection indices, and the identified promising genotypes can serve as valuable genetic resources for breeding lutein rich high-yielding variety.

Keywords: Antioxidant, Correlation coefficients, Heritability, Genetic advance, Lutein

Introduction

Marigold (*Tagetes spp*.) is an important flowering plant of the Asteraceae family; it is widely distributed all over the world [1-2]. Genus *Tagetes* comprises about 55 species [3], out of which, African marigold (*Tagetes erecta* L.) and French marigold (*Tagetes patula* L.) are commercially cultivated with distinct flower colours [1], and another species known as wild marigold or Mexican marigold *(Tagetes minuta* L.*)* is grown for essential oil [4-7]. Marigold flowers originate in South and Central America, with more diversity in Mexico [8-9]. It is an annual blooming herb, erect, widely branching, growing in all seasons up to 1.4 meters [9].

It is mainly grown in Europe, the USA, China, India, the Caribbean, Africa, and Oceania [9]. India dominates global production, accounting for over half of the total production (55-60%), and diverse agro-climatic conditions of India are widely suitable for the commercial cultivation

of marigolds, promoting their widespread cultivation in many states such as Madhya Pradesh, Karnataka, Gujarat, Andhra Pradesh, Maharashtra, Tamil Nadu, Haryana, West Bengal, and Bihar [8]. Among the traditional loose flowers cultivated in India, marigolds hold a prominent position in terms of both area and production. Marigold is being cultivated on about 80 thousand ha of land, with a production of 941.46 MT [10].

It is extensively grown for loose flowers, which vary from yellow to orange, making floral garlands, used as decorations in various social and religious occasions, poultry farming, dye, aromatherapy and several medicinal uses [2, 11, 12].

At present, marigolds are extensively utilized as bedding plants, in hanging baskets and rock gardens, as well as for interior decoration worldwide [9]. Moreover, marigold essential oil is widely appreciated in the perfumery industry for its high value, and marigold in agriculture has been shown to have several significant impacts as a nematicide and insecticide, and also plays a significant role in the attraction of pollinators [13, 11, 14].

Marigold flower petals are considered one of the most vital sources of polyphenols and carotenoids, especially lutein esters, which account for 70–79% of the total carotenoids [1, 15, 16]. The growing interest of researchers in this stunning plant is due to its significant medicinal value, which is attributed to its bioactive compounds, especially for reducing the risk of macular degeneration [1]. It is utilised for various health concerns and is utilised as natural insecticides, insect repellents, herbicides, bactericides and fungicides [11, 9]. CSIR-CIMAP, India, has developed a natural lutein extraction process. Natural lutein has several uses in pharmaceutical and food industries [16, 15], where it is marketed in the form of capsules, nutraceuticals [17], and food colourant [18]. Lutein has also been well documented for its antioxidant, anti-inflammatory, anticancer, and neuroprotective properties, improves immune function, and plays a protective role against cardiovascular disease [1, 9].

Germplasm provides valuable natural allelic variations for genetic analysis and breeding. To ensure sustained breeding, it is crucial to create gene bank collections with genetic and phenotypic characteristics. Furthermore, the scientific community must have easy access to the data and genetic resources to fully utilize the vast amount of information [19]. Marigold, being a cross-pollinated crop, provides considerable scope for exploitation through heterosis [20]. Studies for selection of superior genotypes/ cultivars/varieties for yields, colour, etc. from existing populations have been reported [21-22]. However, the superiority of lutein is yet to be

explored. Success in crop improvement generally depends on the extent of genetic variability [22], diversity, gene action, and the magnitude to which the desirable quantitative traits are heritable [23-25]. Yield and quantitative traits have complex types of inheritance [26], which interact with environments [25]. On the other hand, qualitative traits like bioactive phytochemicals [16], beta-carotene [25], lutein [27], and antioxidants are monogenic traits that have little influence on the environment [25].

For sound breeding efforts, given the importance of *T. erecta,* a deep study of its quantitative and qualitative traits is required to improve cultivation practices, as understanding the magnitude of genetic variation and trait associations can aid in developing improved production techniques, resulting in higher yields and higher quality produce. The marigold species have not been thoroughly studied for high lutein potential genotypes, and studies have usually been carried out only with limited yield attributes.

Based on the above facts, it has been summarised that marigold flowers play a major role in the pharmaceutical industry and are widely used as functional food with a considerable amount of nutrients, bioactive compounds and less risk of anti-nutritional properties. Hence, the objective of the present research on *T. erecta* is to investigate the lutein-rich genetic variability/diversity and its association with other quantitative and qualitative traits. The findings are likely to enhance the plant's medicinal (lutein) and flower commercial value and promote sustainable cultivation practices, pharmaceutical industry development, and recommendations for large-scale cultivation.

Materials and Methods

Experimental sites

The experiment was carried out at the CSIR–Central Institute of Medicinal and Aromatic Plants Research Farm, Lucknow, India, during the rainy season of 2024–2025 to evaluate 29 genotypes, including a check, using a randomised block design with four replications. The experimental site was situated at 26.50° N latitude, 85.50° E longitude, at an altitude of 120 m above mean sea level, and is characterised by a semi-arid subtropical climate with hot summers and cool winters. During the study period, the average weather conditions during the experiment, viz., temperature (18.28^0C to 30.50^0C), humidity (54.25 % - 91.62 %), and rainfall (87.17mm).

respectively. The nursery was raised during the first week of August 2024, and seedlings were hardened by withholding irrigation for 2–3 days prior to transplanting. Thirty-day-old rooted seedlings of different genotypes were transplanted in the field during the first week of September at spacing of 60 × 45 cm and with four replications using Randomized Block Design (RBD). The experimental field was prepared using 10 tons FYM ha^{-1}, and recommended cultural practices were followed to maintain a healthy crop.

Plant materials

The plant material used in this study was collected from the fields of farmer's registered under CSIR-CIMAP's Floriculture Mission program and from various researches organizations in India. The collected plant material is maintained at CSIR-CIMAP for further research purposes. Details of the genotypes and their sources are provided in Table 1.

Observation

Phenotypic traits were used to characterise marigold germplasm based on observable morphological, yield, and quality attributes. Characterisation of the marigold genotypes was carried out in accordance with the DUS (Distinctness, Uniformity, and Stability) guidelines of the Protection of Plant Varieties and Farmers' Rights Authority (PPV&FRA), Government of India (https://plantauthority.gov.in/). Observations were recorded on five randomly selected plants per replication for each of the twenty-nine genotypes. Data were collected at different crop growth stages for the following traits: plant height at 30, 60, and 90 days after transplanting (PH30, PH60, and PH90, respectively); stem diameter (SD; cm); number of primary branches per plant (NPB); number of secondary branches per plant (NSB); days to bud initiation (DBI); days to first flower opening (DFFO); flower length (FL; cm); flower diameter (FD; cm); number of petals per flower (NPF); number of flower pickings (NFP); number of flowers per plant (NF/P); fresh flower weight (FWF; g); flower yield per plant (FYPP; kg); flower yield per plot (FYP; kg); flower yield per hectare (FYH; q ha^{-1}); fresh petal yield (FPY; q ha^{-1}); dry petal yield (DPY; q ha^{-1}). The qualitative attributes assessed were oleoresin content (OC, %); oleoresin yield (OY, kg ha^{-1}); lutein content (LC, %); and lutein yield (LY, kg ha^{-1}).

Quality attributes analysis

For lutein extraction, marigold flowers from all genotypes were harvested from experimental fields at CSIR–CIMAP, Lucknow. Flower petals were manually separated, shade-dried for 7–10

Table 1 List of twenty nine accessions of *Tagetes erecta* L. and their collected places

Treatments	Accessions	Growing region	Morphology	Place of collection	Indian State
T_1	M-1	Lucknow region	Medium plant height, narrow leaf structure, green stem colour, light orange flower	Collected from farmers field	Uttar Pradesh
T_2	M-2	Lucknow region	Medium plant height, narrow leaf structure, red green stem colour, medium orange flower	Collected from farmers field	Uttar Pradesh
T_3	M-3	Lucknow region	Medium plant height, narrow leaf structure, red green stem colour, light orange flower	Collected from farmers field	Uttar Pradesh
T_4	M-4	Lucknow region	Tall plant height, narrow leaf structure, green stem colour, medium orange flower	Collected from farmers field	Uttar Pradesh
T_5	M -5	Lucknow region	Tall plant height, wide leaf structure, green stem colour, medium orange flower	Collected from farmers field	Uttar Pradesh
T_6	M-6	Lucknow region	Medium plant height, wide leaf structure, green stem colour, dark orange flower	Collected from farmers field	Uttar Pradesh
T_7	M-7	Varanshi region	Medium plant height, narrow leaf structure, red green stem colour, dark orange flower	Collected from farmers field	Uttar Pradesh
T_8	M-8	Lucknow region	Medium plant height, medium leaf structure, red green stem colour, light orange flower	Collected from farmers field	Uttar Pradesh
T_9	M-9	Lucknow region	Medium plant height, medium leaf structure, green stem colour, light orange flower	Collected from farmers field	Uttar Pradesh
T_{10}	M-10	Lucknow region	Medium plant height, narrow leaf structure, red green stem colour, dark orange flower	Collected from farmers field	Uttar Pradesh
T_{11}	M -11	Lucknow region	Tall plant height, wide leaf structure, green stem colour, light orange flower	Collected from farmers field	Uttar Pradesh
T_{12}	M-12*	BCKV, West Bengal	Medium plant height, narrow leaf structure, green stem colour, light orange flower	Procured form BCKV, West Bengal	West Bengal
T_{13}	M-13*	IARI, New Delhi	Medium plant height, wide leaf structure, red stem colour, medium orange flower	Procured form IARI, New Delhi	New Delhi
T_{14}	M-14*	BCKV, West Bengal	Medium plant height, narrow leaf structure, red green stem colour, dark orange flower	Procured form BCKV, West Bengal	West Bengal
T_{15}	M-15	Lucknow region	Tall plant height, wide leaf structure, green stem colour, medium orange flower	Collected from farmers field	Uttar Pradesh
T_{16}	M-16	Bengaluru region	Tall plant height, narrow leaf structure, green stem colour, medium orange flower	Collected from farmers field	Karnataka
T_{17}	M-17	Bengaluru region	Medium plant height, wide leaf structure, red green stem colour, medium orange flower	Collected from farmers field	Karnataka
T_{18}	M-18	Bengaluru region	Medium plant height, wide leaf structure, green stem colour, light orange flower	Collected from farmers field	Karnataka
T_{19}	M-19*	Bengaluru region	Tall plant height, narrow leaf structure, green stem colour, dark orange flower	Procured form IIHR, Bengaluru	Karnataka
T_{20}	M-20	Bengaluru region	Tall plant height, wide leaf structure, green stem colour, dark orange flower	Collected from farmers field	Karnataka
T_{21}	M-21	Bengaluru region	Medium plant height, wide leaf structure, red green stem colour, light orange flower	Collected from farmers field	Karnataka
T_{22}	M-22	Varanshi region	Medium plant height, wide leaf structure, green stem colour, light orange flower	Collected from farmers field	Uttar Pradesh
T_{23}	M-23	Lucknow region	Tall plant height, narrow leaf structure, green stem colour, medium orange flower	Collected from farmers field	Uttar Pradesh
T_{24}	M-24	Lucknow region	Medium plant height, wide leaf structure, green stem colour, medium orange flower	Collected from farmers field	Uttar Pradesh
T_{25}	M-25	Lucknow region	Medium plant height, narrow leaf structure, red green stem colour, medium orange flower	Collected from farmers field	Uttar Pradesh
T_{26}	M-26	Lucknow region	Medium plant height, wide leaf structure, red green stem colour, medium orange flower	Collected from farmers field	Uttar Pradesh
T_{27}	M-27	Varanshi region	Medium plant height, wide leaf structure, red green stem colour, medium orange flower	Collected from farmers field	Uttar Pradesh
T_{28}	M-28	Lucknow region	Medium plant height, wide leaf structure, green stem colour, medium orange flower	Collected from farmers field	Uttar Pradesh
T_{29}	M-29	Lucknow region	Medium plant height, wide leaf structure, green stem colour, medium orange flower	Collected from farmers field	Uttar Pradesh

*Released Variety by Government Institution. Bidhan Chandra Krishi Viswavidyalaya, West Bengal, Indian Agricultural Research Institute, Pusa - New Delhi, Indian Institute of Horticultural Research, Bengaluru- Karnataka.

157 days, and ground into a fine powder. Xanthophyll (free lutein) was extracted using the method
158 previously reported. Briefly, dried powdered marigold petals (10g × 3) were extracted with
159 hexane (1:20) by maceration for 24 hours. The extract was filtered and concentrated to obtain
160 oleoresin. Oleoresin was homogenised with hexane (1:5) and saponified using 20% ethanolic
161 KOH for 1 hour at 50-55°C. The saponified mixture was cooled to room temperature, 100 mL of
162 distilled water was added, and the mixture was stirred for 10 min. The mixture was kept in the
163 dark for 1 hour and then extracted with 200 mL of diethyl ether. The organic layer was washed
164 with distilled water and concentrated using a rotary evaporator to yield free xanthophyll (free
165 lutein) [16].

166 **Statistical analysis**

167 The pooled data were then subjected to analysis of variance (ANOVA), differences among
168 germplasm followed by Duncan's Multiple Range Test (DMRT) with the aid of Statistical
169 Analysis System (SAS) Software [29, 20].. Genotypic and phenotypic coefficients of variation
170 (GCV and PCV) were estimated using the formulae proposed by [29]. Broad-sense heritability
171 and genetic advance as a percentage of the mean were estimated according to [30]. Pearson's
172 correlation coefficients were computed following the methods suggested by [31-32]. Path
173 coefficient analysis was performed using the methodology proposed by [33]. Correlations and
174 principal component analysis (PCA) were subjected to analysis using R software. PCA biplots,
175 variable plots, and individual plots were generated using the R packages devtools, ggplot2, and
176 factoextra. Trait correlations were analysed using the metan package in R, while principal
177 component scores and descriptive statistical analyses were obtained using PAST v4.04 software.

178 **Results and discussion**

179 Genetic diversity is an essential tool for both genetic improvement and the development of
180 high-yielding varieties [13, 20]. To better understand genetic variability and genotypic and
181 phenotypic relationships, we examined lutein-rich genetic variation in twenty-nine African
182 marigold genotypes. The pooled ANOVA results for all 23 traits (Table 2) indicate significant
183 variation ($P<0.01$) among the twenty-nine genetic stocks. The combined use of passport,
184 phenotypic, and genetic information, and seed stock, when coupled with ease of access, makes
185 this collection an effective tool for genetic diversity analysis [19, 8].

Table 2. Analysis of variance (ANOVA) for twenty three traits of *Tagetes erecta* L. germplasm.

Traits	Source of Variation (Mean sum of square)		
	Replication (df=3)	Genotypes (df = 28)	Error (df= 84)
PH 30 DAT	4.161	1922.329**	633.839
PH 60 DAT	59.165	15627.747**	3250.335
PH 90 DAT	89.954	18247.318**	2266.046
SD	0.044	3.028 **	4.770
NPB	22.351	1621.589**	545.742
NSB	9.172	1795.408**	606.828
DBI	3.931	842.583**	300.069
DFFO	24.299	743.005**	281.701
FL	0.084	63.731**	32.414
FD	43.837	6919.112**	619.440
NPF	626.138	433666.388**	7641.862
NFP	6.920	14.674**	27.081
NF/P	76.161	3656.549**	1612.506
FWF	17.859	1341.703**	135.627
FYPP	0.029	0.836**	0.217
FY/P	7.653	212.396**	55.823
FYH	4102.89	113792.89**	29923.51
FYP	1477.489	40965.022**	10772.013
DPY	14.806	409.571**	107.704
OC	0.026	259.918**	0.292
OY	579.325	18236.909**	3900.970
LC	0.003	14.163**	0.012
LY	18.411	869.259**	101.085

*p<0.05% level of significance, **p<0.01% level of significance, Plant height (PH30, PH60, and PH90 days), stem diameter (SD; cm), number of primary branches per plant (NPB), number of secondary branches per plant (NSB), days to bud initiation (DBI), days to first flower opening (DFFO), flower length (FL; cm), flower diameter (FD; cm), number of petals per flower (NPF), number of flower pickings (NFP), number of flowers per plant (NF/P), fresh flower weight (FWF; g), flower yield per plant (FYPP; kg), flower yield per plot (FYP; kg), flower yield per hectare (FYH; q ha^{-1}), fresh petal yield (FPY; q ha^{-1}), dry petal yield (DPY; q ha^{-1}). The qualitative attributes assessed were oleoresin content (OC, %), oleoresin yield (OY, kg ha^{-1}), lutein content (LC, %), and lutein yield (LY, kg ha^{-1}).

The individual performance of quantitative and qualitative traits of twenty-nine marigold genotypes is presented in Table 3. Analysis of variance indicated significant genotypic effects for most traits, and mean separation was carried out using the least significant difference (LSD) test at $P \leq 0.05$. Flower yield per hectare differed significantly among genotypes, ranging from 23.21 q ha^{-1} in Pusa Narangi to 154.07 q ha^{-1} in M-1. Several genotypes, including M-1, M-7, M-23, M-20, M-2, M-10, M-12, M-9, M-19, and M-4, recorded significantly higher yields than the check genotypeM-13 (Pusa Narangi) (Figure 1a). These results could be due to the vigorous flower size, which attributes more gene action and environmental conditions that critically

enhance the yield. The genotypes exhibited substantial variability in flower yield traits, which was attributed to the number of primary and secondary branches, flower diameter, and number of petals per flower. These variations could be used for the identification of promising genotypes for increasing yield and yield-attributing traits, which reflect the economic condition of growers [34, 2].

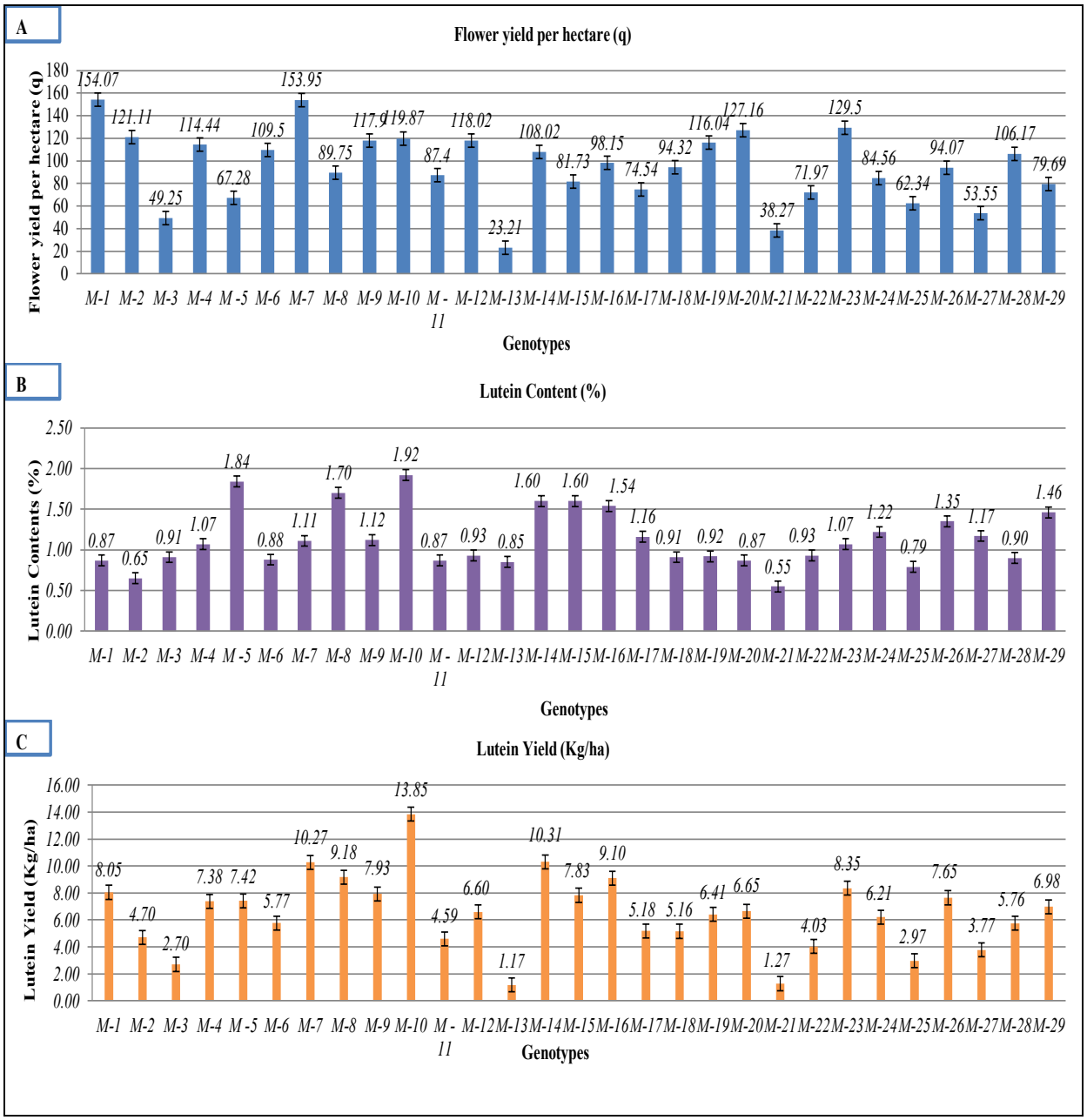


Figure 1a-c. Mean performance of different economic traits a. flower yield (q/ha), b. lutein content (%), and c. lutein yield (Kg/ha) in the genotypes of *Tagetus erecta* L.

225 **Table 3. Pooled mean performance of the twenty three quantitative and qualitative traits in twenty nine genotypes of *Tageteserecta* L.**

Accessions Name	PH @ 30 DAT	PH @ 60 DAT	PH @ 90 DAT	SD	NPB	NSB
M-1	42.66 ± 2.05 bcde	67.33 ± 2.05 ijk	71.33 ±1.70 l	1.13 ± 0.28 g	13.66 ± 0.94 cdefg	21.33± 3.85 abc
M-2	47.00 ± 1.41 a	81.00 ± 7.11 def	94.33 ± 8.34 def	1.20 ± 0.21 efg	10.66 ± 3.85 fghij	18.00 ± 4.32 cdefg
M-3	44.00 ± 1.63 abc	62.33 ± 5.43 kl	71.66 ± 6.84 kl	1.20 ± 0.25 efg	16.00 ± 4.94 abc	19.66 ± 1.7 0 bcde
M-4	45.33 ± 6.18 abc	68.66 ± 1.24hijk	103.33 ± 0.94 bc	1.53 ± 0.24 abcde	9.66 ± 3.30 hijk	15.33 ± 2.49 fg
M -5	44.66 ± 0.94 abc	82.00 ± 8.52 def	110.00 ± 5.71 ab	1.53 ± 0.09 abcde	5.33 ± 1.24 mn	11.00 ± 2.16 hi
M-6	39.00 ± 2.16 efg	62.66 ± 2.62 jkl	75.33 ± 2.49 jkl	1.16± 0.28 fg	7.66 ± 1.24 jklm	14.33 ± 1.70 gh
M-7	45.00 ± 1.63 abc	84.33 ± 0.94 cde	90.66 ± 4.64 efg	1.23 ± 0.17 defg	9.33 ± 2.05 ijkl	15.66 ± 1.70 fg
M-8	44.00 ± 2.94 abc	67.33 ± 2.62 ijk	75.00 ± 4.89 jkl	1.20 ± 0.08 efg	11.00 ± 3.74 efghij	16.33 ± 2.62 defg
M-9	42.00 ± 2.94 cdef	77.00 ± 8.60 efgh	82.66 ± 8.99 hi	1.33 ± 0.26 bcdefg	9.00 ± 3.26 ijkl	15.66 ± 4.02 fg
M-10	43.66 ± 1.24 abcd	75.66 ± 4.92 efghi	87.33 ± 9.03 fgh	1.20 ± 0.28 efg	8.66 ± 2.05 jklm	15.33 ± 2.49 fg
M -11	44.33 ± 4.19 abc	96.66 ± 8.99 ab	108.00 ± 5.71 ab	1.46 ± 0.17 abcdefg	9.33 ± 4.19 ijkl	15.33 ± 4.11 fg
M-12	43.33 ± 2.86 abcd	74.33 ± 1.70 fghi	89.66 ± 2.62 efgh	1.45 ± 0.41 abcdefg	15.66 ± 4.49 abcd	20.00 ± 4.08 bcd
M-13	44.33 ± 1.24 abc	82.00 ± 6.97 def	92.00 ± 1.63 ef	1.40 ± 0.21 abcdefg	3.66 ± 0.94 n	7.66 ± 1.24 i
M-14	36.66 ± 4.11 gh	76.00 ± 1.41 efghi	92.00 ± 2.16 ef	1.58 ± 0.13 abc	14.33 ± 1.70 bcde	20.00 ± 3.26 bcd
M-15	46.33 ± 2.86 ab	75.00 ± 12.19 fghi	104.00 ± 2.16 bc	1.45 ± 0.30 abcdefg	13.33 ± 0.94 cdefg	19.66 ± 1.24 bcde
M-16	42.33 ± 2.86 cdef	98.33 ± 8.65 a	105.00± 8.52 bc	1.62 ± 0.17 ab	17.33 ± 1.24 ab	24.66 ± 2.62 a
M-17	44.33 ± 2 .49 abc	67.33 ± 3.09 ijk	79.00 ± 5.71 ij	1.32 ± 0.29 bcdefg	6.00 ± 2.16 lmn	10.66 ± 2.49 hi
M-18	40.00 ± 1.63 defg	71.33 ± 1.70 ghij	82.66 ± 3.30 hi	1.22 ± 0.17 defg	7.00 ± 2.16 klmn	10.66 ± 3.30 hi
M-19	36.66 ± 3.68 gh	92.66 ± 5.79 abc	114.00 ± 5.09 a	1.60 ± 0.35 ab	17.33 ± 2.05 ab	23.00 ± 1.63 ab
M-20	42.00 ± 0.81 cdef	88.66 ± 3.39 bcd	106.33 ± 3.09 bc	1.25 ± 0.35 cdefg	19.00 ± 1.41 a	24.33 ± 0.94 a
M-21	42.33 ± 2.05 cdef	78.33 ± 8.49 efg	83.00 ± 6.16 hi	1.17 ± 0.17 fg	12.33 ± 3.09 defghi	19.00 ± 2.16 cdef
M-22	34.33 ± 1.70 hi	52.33 ± 2.05 m	84.66 ± 2.49 ghi	1.37 ± 0.15 abcdefg	10.33 ± 0.47 ghijk	17.66 ± 2.05 cdefg
M-23	39.00 ± 2.94 efg	69.00 ± 10.67 hijk	100.00 ± 3.55 cd	1.55 ± 0.18 abcd	14.00 ± 1.63bcdef	20.33 ± 1.24 bc
M-24	43.33 ± 2.86 abcd	78.33 ± 5.90 efg	93.66 ± 4.19 def	1.67 ± 0.09 a	13.66 ± 2.62 cdefg	18.66 ± 2.62 cdef
M-25	34.33 ± 2.86 hi	70.33 ±6.12 ghijk	69.66 ± 7.58 l	1.50 ± 0.31 abcdef	11.00 ± 4.32 efghij	18.00 ± 3.26 cdefg
M-26	38.66 ± 1.88 fg	71.33 ± 10.78 ghij	95.33 ± 4.11 de	1.45 ± 0.12 abcdefg	13.00 ± 1.41 cdefgh	19.66 ± 1.24 bcde
M-27	42.66 ± 2.05 bcde	69.33 ± 4.19 hijk	91.66 ± 6.23 efg	1.29 ±0.23 bcdefg	10.36 ± 1.21 ghijk	17.66 ± 1.24 cdefg
M-28	34.00 ± 2.94 hi	55.00 ± 4.08 lm	74.33 ± 4.92 jkl	1.20 ± 0.16 efg	8.06 ± 0.73 jklm	16.33 ±2.05 defg
M-29	31.00 ± 2.34 i	50.16 ± 1.65 m	78.66 ± 1.70 ijk	1.22 ± 0.17 defg	13.66± 0.49 jklm	16.00 ± 3.55 efg
Mean	41.29	73.96	89.84	1.36	11.22	17.31
LSD @ 0.05 %	3.86	8.74	7.30	0.33	3.58	3.77

226 Means followed by the same letter with in the same column are statistically not different at P<0.05 according to Duncan's multiple range test (DMRT). PH 30 DAT = plant height at 30 DAT (cm), PH 60 DAT =
227 plant height at 60 DAT (cm), PH 90 DAT= plant height at 90 DAT (cm), SD = stem diameter (cm), NPB = number of primary branches per plant, NSB = number of secondary branches per plant.

228

229 Table 3. Continued…..

Accessions Name	DBI	DFFO	FL	FD	NPF	NFP
M-1	38.66 ± 0.94 hijkl	50.33 ± 1.24 defgh	3.63 ± 0.81 defgh	69.95 ± 2.43 b	179.33 ± 8.21 jk	4.00 ± 0.81 abc
M-2	39.00 ± 2.16 ghijk	49.00 ± 2.94 fghijk	3.60 ± 0.64 efgh	65.98 ± 0.56 cd	218.33 ± 8.49 d	3.33 ± 0.47cd
M-3	39.66 ± 1.24 fghij	51.66 ± 2.05 bcde	2.96 ± 1.19 h	53.12 ± 2.46 n	180.66 ± 8.21 ikj	3.33 ± 0.47 cd
M-4	39.33 ± 0.94 fghijk	50.66 ± 1.24 cdefg	4.83 ± 0.85 bc	66.68 ± 0.73 bc	245.33± 7.54 c	3.66 ± 0.94 bcd
M -5	39.33 ± 2.62 fghijk	47.66 ± 3.09 ijklmn	4.50 ± 0.16 bcd	65.81 ± 1.54 cde	181.00 ± 7.78 ijk	3.66 ± 0.47 bcd
M-6	38.33 ± 1.24 hijkl	47.66 ± 1.70 ijklmn	3.86 ± 0.94 defg	76.22 ± 1.26 a	171.66 ± 6.23 k	3.33 ± 0.47 cd
M-7	37.00 ± 0.81 kl	49.33 ± 1.24 efghij	3.10 ± 0.37 gh	76.75 ± 2.58 a	306.66 ± 12.27 b	4.00 ± 0.81 abc
M-8	37.66 ± 1.24 ijkl	51.00 ± 0.81 bcdef	4.17 ± 0.48 cdef	55.90 ± 1.76 lmn	185.66 ± 17.25 ghij	3.33 ± 0.47 cd
M-9	41.33 ± 2.49 defg	51.66 ± 1.70 bcde	4.96 ± 0.19 bc	74.07 ± 2.93 a	191.66 ± 6.23 fghij	3.33 ± 0.47 cd
M-10	43.66 ± 2.62 bcd	53.00 ± 2.16 abc	5.20 ± 0.45 b	77.00 ± 1.52 a	446.66 ± 20.54 a	3.00 ± 0.00 d
M -11	37.33 ± 2.05 jkl	46.33 ± 2.05 lmn	6.40 ± 0.21 a	67.52 ± 2.17 bc	181.00 ± 6.97 ijk	3.66 ±0.94 bcd
M-12	40.00 ± 1.63 efghi	48.33 ± 1.24 ghijkl	4.50 ± 0.28 bcd	57.02 ± 4.62 jklm	248.33 ± 13.12 c	3.66 ± 0.47 bcd
M-13	48.33 ± 2.62 a	55.33 ± 2.05a	4.36 ± 0.17 bcde	60.32 ± 4.62 ghijk	200.00 ± 8.16 ef	4.00 ± 0.81 abc
M-14	39.00 ± 2.16 ghijk	51.00 ± 2.16 bcdef	3.76 ± 0.20 defgh	56.51 ± 1.84 klmn	181.33 ± 3.39 ijk	3.66 ± 0.47 bcd
M-15	38.66 ± 2.49 hijkl	48.00 ± 2.94hijklm	3.90 ±0.94 defg	53.67 ± 1.19 mn	140.66 ± 3.30 m	4.33 ±0.47 ab
M-16	44.00 ± 1.63 bc	52.00 ± 2.16 bcd	3.53 ± 0.04 efgh	58.85 ± 4.21hijkl	196.00 ± 4.32 fgh	3.66 ± 0.47 bcd
M-17	37.00 ± 0.81 kl	47.33 ± 1.88 ijklmn	3.20 ± 0.28 gh	58.00 ± 3.08 ijkl	196.66 ± 12.47 efgh	4.00 ± 0.81 abc
M-18	38.66 ± 0.94 hijkl	46.33 ± 1.24 lmn	4.36 ± 0.34 bcde	64.50 ±2.09 cdef	210.00 ± 9.79 de	4.66 ± 0.47a
M-19	42.33 ± 2.05 bcde	49.66 ± 2.86 defghi	4.10 ± 0.49cdef	60.84 ± 3.04 fghi	251.66 ± 6.23 c	3.33 ±0.47 cd
M-20	37.33 ± 1.70 jkl	46.66 ± 1.70 klmn	3.63 ± 0.49 defgh	60.93 ± 2.31 fghi	196.00 ± 13.58 fgh	4.00 ± 0.81 abc
M-21	39.00 ± 2.16 ghijk	47.00 ±0.81 ijklmn	2.96 ± 0.20 h	44.52 ± 0.39 p	81.00 ±2.94 o	3.33 ± 0.47 cd
M-22	40.33 ± 1.70 efgh	49.00 ± 0.81 fghijk	3.33 ± 0.77 fgh	58.10 ± 2.67 ijkl	193.33 ± 10.27 fghi	4.00 ± 0.81 abc
M-23	44.66 ± 0.94 b	53.33 ±0.94 ab	4.40 ± 1.06 bcde	63.74 ± 3.55 cdefg	198.00 ± 6.68 efg	3.66 ±0.94 bcd
M-24	38.00 ± 1.63 hijkl	45.33 ± 1.24 n	3.70 ± 0.49 defgh	62.14 ± 1.30 efgh	155.00 ± 4.08 l	3.66 ± 0.47 bcd
M-25	37.33 ± 0.94 jkl	45.66 ± 0.47 mn	4.10 ± 0.37 cdef	60.52 ± 1.19 ghij	205.00 ± 10.80 def	3.33 ± 0.47 cd
M-26	37.66 ± 0.47 ijkl	45.66 ± 1.24 mn	2.96 ± 0.41h	58.93 ± 1.15 hijkl	183.33± 8.49hijk	3.66 ±0.47 bcd
M-27	41.66 ± 2.86 cdef	49.66 ± 2.86 defghi	3.66 ± 0.62 defgh	48.70 ± 5.85 o	125.00 ± 12.32 n	3.33 ± 0.47 cd
M-28	41.33 ± 3.39 defg	48.66 ± 1.70 fghijkl	4.30 ± 0.43 cde	63.94 ± 3.94 cdefg	196.33 ±10.33 fgh	4.00 ± 0.81 abc
M-29	36.33 ± 1.24 l	46.33 ± 1.70 lmn	4.10 ± 0.08 cdef	62.40 ±3.25 defgh	192.33 ± 7.13fghij	3.66 ± 0.47 bcd
Mean	39.76	49.09	4.00	62.16	201.31	3.68
LSD @ 0.05 %	2.65	2.57	0.87	3.81	13.41	0.79

230 Means followed by the same letter with in the same column are statistically not different at P<0.05 according to Duncan's multiple range test (DMRT). DBI = days to bud initiation, DFFO = days to first
231 flower opening, FL= flower length (cm), FD = flower diameter (cm), NPF = number of petals per flower, NFP= number of flower pickings
232

Table 3. Continued…..

Accessions Name	NFP	FWF	FYPP	FYP	FYH	FPY
M-1	34.66 ± 0.94 b	12.00 ± 0.81 bcde	0.41 ± 0.03 a	6.65 ± 0.48 a	154.07 ± 11.10 a	92.442 ± 6.66 a
M-2	25.66 ± 3.30 ghij	12.66 ± 1.24 bc	0.33 ± 0.06 bc	5.23 ± 1.05 bc	121.11 ± 24.41 bc	72.668 ± 14.64 bc
M-3	30.33 ± 3.30 bcdefg	4.33 ± 0.94 m	0.13 ± 0.04 mno	2.12 ± 0.60 lmn	49.25 ± 13.88 mno	29.558 ± 8.32 mno
M-4	24.00 ± 1.63 hij	12.83 ± 0.62 bc	0.30 ± 0.03 bcde	4.94 ± 0.57 bcde	114.44 ± 13.17 bcde	68.668 ± 7.90 bcde
M -5	17.33 ± 2.62 kl	10.50 ± 0.81 efg	0.18 ± 0.02jklm	2.90 ± 0.46 ijkl	67.28 ± 10.63 jklm	40.370 ± 6.37 jklm
M-6	22.66 ± 0.94 ijk	13.00 ± 1.47 b	0.29 ± 0.04 bcdef	4.73 ± 0.69 bcdef	109.50 ± 16.03 bcdef	65.702 ± 9.61 bcdef
M-7	21.66 ±1.70 jk	19.33 ± 2.05 a	0.41 ± 0.01 a	6.65 ± 0.28 a	153.95 ± 6.51 a	92.372 ± 3.90 a
M-8	27.00 ± 1.63 efghij	9.00 ± 0.40 ghij	0.24 ± 0.00 efghij	3.87 ± 0.05 efghi	89.75 ± 1.37 efghij	53.852 ± 0.82 efghij
M-9	23.33 ± 4.02 hijk	13.66 ± 3.30 b	0.32 ± 0.08 bcd	5.09 ± 1.33 bcd	117.90 ± 30.99 bcd	70.740 ± 18.59
M-10	24.66 ± 1.88 ghij	13.16 ± 1.17 b	0.32 ± 0.02 bcd	5.17 ± 0.45 bcd	119.87 ± 10.64 bcd	71.925 ± 6.39 bcd
M -11	23.66 ± 4.19 hij	10.33 ± 2.05 efgh	0.23 ± 0.01 fghijk	3.77 ± 0.17 fghij	87.40 ± 3.96 fghijk	52.445 ± 2.38 fghijk
M-12	29.00 ± 2.94 bcdefgh	11.16 ±2.09 cdef	0.32 ± 0.03 bcd	5.10 ± 0.55 bcd	118.02 ± 12.91 bcd	70.815 ± 7.75 bcd
M-13	14.33 ± 1.70 kl	4.33 ± 0.47 m	0.06 ± 0.01 o	1.00 ± 0.21 n	23.21 ± 4.88 o	13.928 ± 2.93 o
M-14	27.00 ± 5.09 efghij	10.83 ± 0.23 def	0.29 ± 0.05 bcdef	4.66 ± 0.81 bcdefg	108.02 ± 18.94 bcdefg	64.815 ± 11.36 bcdefg
M-15	34.33 ± 6.23 bc	6.50 ± 0.40 l	0.22 ± 0.02 ghijk	3.53 ± 0.44 ghij	81.73 ± 10.28 ghijk	49.038 ± 6.17 ghijk
M-16	32.00 ± 3.74 bcdef	8.33 ± 0.47 ijk	0.26 ± 0.02 cdefgh	4.24 ± 0.29 cdefgh	98.15 ± 6.81 cdefghi	58.890 ± 4.08 cdefghi
M-17	27.00 ± 4.32 efghij	7.41 ± 1.00 jkl	0.20 ± 0.04hijklm	3.22 ± 0.75 hijkl	74.54 ± 17.49 ijklm	44.722 ± 10.50 ijklm
M-18	28.66 ± 6.60 bcdefghi	8.66 ± 2.62 hij	0.25 ± 0.10 defghi	4.07 ± 1.70 defgh	94.32 ± 39.39 defghi	56.592 ± 23.63 defghi
M-19	32.33 ± 2.62 bcde	9.66 ± 0.47 fghi	0.31 ± 0.03 bcde	5.01 ± 0.58 bcde	116.04 ± 13.63 bcde	69.630 ± 8.18 bcde
M-20	44.66 ± 15.17 a	7.33 ± 1.70 jkl	0.34 ± 0.17 b	5.49 ± 2.87 b	127.16 ± 66.64 b	76.298 ± 39.98 b
M-21	26.00 ± 0.81 fghij	4.00 ± 0.81 m	0.10 ± 0.02 no	1.65 ± 0.28 mn	38.27 ± 6.65 no	22.962 ± 3.99 no
M-22	26.33 ± 2.05 efghij	7.33 ± 1.70 jkl	0.19 ± 0.05 ijklm	3.11 ± 0.85 hijkl	71.97 ± 19.81 ijklm	43.188 ± 11.89 ijklm
M-23	28.33 ± 0.47 cdefghi	12.33 ± 0.94 bcd	0.35 ± 0.02 ab	5.59 ± 0.47 ab	129.50 ± 11.08 ab	77.702 ± 6.65 ab
M-24	33.33 ± 4.02 bcd	6.83 ± 0.23 kl	0.23 ± 0.02 fghijk	3.65 ± 0.52 fghij	84.56 ± 12.16 fghijk	50.740 ± 7.30 fghijk
M-25	25.00 ± 2.16 ghij	6.66 ± 1.24 kl	0.16 ± 0.04 klmn	2.69 ± 0.68 jklm	62.34 ± 15.84 klmn	37.410 ± 9.50 klmn
M-26	30.66 ± 2.62 bcdefg	8.33 ± 0.94 ijk	0.25 ± 0.02defghi	4.06 ± 0.39 defgh	94.07 ± 9.08defghi	56.442 ± 5.45defghi
M-27	32.00 ± 7.11 bcdef	4.54 ± 0.19 m	0.14 ± 0.02 lmn	2.31 ± 0.46 klm	53.55 ± 10.71 lmn	32.135 ± 6.43 lmn
M-28	28.00 ± 3.26 defghi	10.16 ± 0.85 fgh	0.29 ± 0.05bcdefg	4.59 ± 0.82 bcdefg	106.17 ± 18.98 bcdefgh	63.702 ± 11.39 bcdefgh
M-29	28.66 ± 1.70 bcdefghi	7.50 ± 0.40 jkl	0.21 ± 0.01 hijkl	3.44 ± 0.30 hijk	79.69 ± 6.97hijkl	47.815 ± 4.18 hijkl
Mean	27.68	9.41	0.256	4.09	94.69	56.81
LSD @ 0.05 %	6.16	1.78	0.07	1.14	26.54	15.92

Means followed by the same letter with in the same column are statistically not different at P<0.05according to Duncan's multiple range test (DMRT). NFP = number of flowers per plant, FWF = fresh flower weight (g), FYPP = flower yield per plant (kg), FYP = flower yield per plot (kg), FYH = flower yield per hectare (q), FPY= fresh petal yield per hectare (q).

Table 3. Continued…..

Accessions Name	DPY	OC	OY	LC	LY
M-1	9.242 ± 0.66 a	4.190 ± 0.08 rs	38.782 ± 3.47 defgh	0.87 ± 0.00 p	8.05 ± 0.62 cde
M-2	7.268 ± 1.46 bc	3.950 ± 0.08 v	28.712 ± 5.83 ij	0.65 ± 0.00 s	4.70 ± 0.93 jkl
M-3	2.958 ± 0.83 mno	4.508 ± 0.07 q	13.280 ± 3.65 lm	0.91 ± 0.00 mno	2.70 ± 0.75 mn
M-4	6.867 ± 0.78 bcde	7.272 ± 0.07 e	49.913 ± 5.55 abc	1.07 ± 0.00 k	7.38 ± 0.85 defg
M -5	4.037 ± 0.63 ijklm	8.037 ± 0.07 b	32.455 ± 5.18 efghij	1.84 ± 0.00 b	7.42 ± 1.17 defg
M-6	6.570 ± 0.96 bcdef	4.040 ± 0.03 u	26.560 ± 4.01 ijk	0.88 ± 0.00 p	5.77 ± 0.81 hijk
M-7	9.240 ± 0.39 a	6.150 ± 0.08 i	56.830 ± 3.02 a	1.11 ± 0.00 j	10.27 ± 0.48 b
M-8	5.388 ± 0.08 efghij	6.200 ±0.08 i	33.390 ± 0.79 efghi	1.70 ± 0.00 c	9.18 ± 0.16 bc
M-9	7.073 ± 1.86 bcd	5.650 ± 0.08 l	39.840 ± 10.10 defg	1.12 ± 0.00 j	7.93 ± 2.11 cdef
M-10	7.190 ± 0.64 bcd	4.060 ± 0.04 tu	29.200 ± 2.57 ij	1.92 ± 0.00 a	13.85 ± 1.20 a
M -11	5.245 ± 0.23 fghijk	7.772 ± 0.04 cd	40.758 ± 1.63 cde	0.87 ± 0.00 p	4.59 ± 0.23 kl
M-12	7.082 ± 0.77 bcd	4.742 ± 0.04 p	33.592 ± 3.71 efghi	0.93 ± 0.02 lm	6.60 ± 0.85 efghi
M-13	1.393 ± 0.29 o	7.692 ± 0.06 d	10.727 ± 2.31 lm	0.85 ± 0.00 q	1.17 ± 0.24 n
M-14	6.482 ± 0.13 bcdefg	8.248 ± 0.07 a	53.382 ± 9.04 ab	1.60 ±0.05 d	10.31 ± 1.52 b
M-15	4.902 ± 0.62 ghijk	8.190 ± 0.07 a	40.202 ± 5.36 def	1.60 ± 0.00 d	7.83 ± 0.98 cdef
M-16	5.890 ± 0.48 cdefghi	7.783 ± 0.06 c	45.860 ± 3.56 bcd	1.54 ± 0.00 e	9.10 ± 0.62 bc
M-17	4.472 ± 1.05 ijklm	6.058 ± 0.06 j	27.150 ± 6.66 ijk	1.16 ± 0.00 i	5.18 ± 1.24 ijkl
M-18	5.660 ± 2.36 defghi	4.140 ± 0.02 st	23.395 ± 9.67 jk	0.91 ± 0.00 no	5.16 ± 2.14 ijkl
M-19	6.963 ± 0.81 bcde	5.142 ± 0.03 o	35.787 ± 3.97 efghi	0.92 ± 0.00 lmn	6.41 ± 0.79 fghi
M-20	7.630 ± 3.99 b	6.780 ± 0.04 f	51.817 ± 27.38 ab	0.87 ± 0.00 p	6.65 ± 3.47 efghi
M-21	2.297 ± 0.40 no	3.180 ± 0.06 w	7.287 ± 1.18 m	0.55 ± 0.00 t	1.27 ± 0.21 n
M-22	4.320 ± 1.18 ijklm	4.270 ± 0.05 r	18.372 ± 4.82 kl	0.93 ± 0.00 l	4.03 ± 1.13 im
M-23	7.770 ± 0.66 ab	6.692 ± 0.06 g	51.995 ± 4.29 ab	1.07 ± 0.00 k	8.35 ± 0.67 cd
M-24	5.072 ± 0.73 fghijk	5.938 ± 0.02 k	30.137 ± 4.44 hij	1.22 ± 0.00 h	6.21 ± 0.89 ghij
M-25	3.743 ± 0.95 klmn	8.020 ± 0.05 b	30.058 ± 7.85 hij	0.79 ± 0.00 r	2.97 ± 0.74 m
M-26	5.642 ± 0.54 defghi	5.390 ± 0.05 n	30.390 ± 2.58 ghij	1.35 ± 0.00 g	7.65 ± 0.77 cdefg
M-27	3.212 ± 0.64lmn	5.688 ±0.04 l	18.250 ± 3.51 kl	1.17 ± 0.00 i	3.77 ± 0.77 im
M-28	6.370 ± 1.14 bcdefgh	5.530 ± 0.03 m	35.250 ± 6.43 efghi	0.90 ±0.00 o	5.76 ± 1.00hijk
M-29	4.783 ± 0.42 hijkl	6.508 ± 0.02 h	31.110 ± 2.72 fghij	1.46 ± 0.00 f	6.98 ± 0.58 defgh
Mean	5.68	5.92	33.26	1.132	6.46
LSD @ 0.05 %	1.59	0.08	9.58	0.01	1.54

Means followed by the same letter with in the same column are statistically not different at P<0.05 according to Duncan's multiple range test (DMRT). DPY = dry petal yield per hectare, OC = oleoresin content (q), OY = oleoresin yield (kg), LC = lutein content (%), LY = lutein yield (kg).

Table 4 Genetic parameters of twenty three traits of *Tagetes erecta* L. genotypes.

Traits	Mean	Range		CV	GCV (%)	PCV (%)	h^2_{BS}(%)	GA	GAM (%)
		Minimum	Maximum						
PH 30 DAT	41.28	28	54	6.65	9.46	11.57	66.93	6.58	15.95
PH 60 DAT	73.95	48	108	8.41	15.40	17.55	77.04	20.60	27.85
PH 90 DAT	89.83	59	121	5.78	13.91	15.06	85.27	23.77	26.46
SD	1.36	0.8	2	17.45	8.31	19.31	18.44	0.10	7.34
NPB	11.21	3	23	22.72	31.96	39.21	66.42	6.01	53.65
NSB	17.31	6	27	15.52	21.78	26.75	66.31	6.32	36.55
DBI	39.75	35	52	4.75	6.47	8.03	64.98	4.27	10.75
DFFO	49.09	44	58	3.73	4.90	6.16	63.34	3.94	8.04
FL	4.00	1.3	6.6	15.51	17.16	23.13	55.04	1.05	26.23
FD	62.16	40.9	80.38	4.36	12.45	13.19	89.04	15.04	24.20
NPF	201.31	78	470	4.73	30.81	31.18	97.69	126.32	62.75
NFP	3.67	3	5	15.43	6.09	16.59	13.52	0.16	4.60
NF/P	27.67	12	66	15.82	19.06	24.78	59.19	8.36	30.21
FWF	9.40	3	22	13.50	36.16	38.60	87.75	6.56	69.80
FYPP	0.25	0.04	0.59	19.93	32.14	37.82	72.23	0.14	56.28
FY/P	4.09	0.76	9.50	19.93	32.16	37.83	72.25	2.30	56.31
FYH	94.68	17.77	220	19.93	32.15	37.83	72.23	53.30	56.29
FYP	56.81	10.66	132	19.93	32.15	37.83	72.23	31.98	56.29
DPY	5.68	1.06	13.2	19.93	32.14	37.83	72.23	3.19	56.29
OC	5.92	3.1	8.34	0.99	25.70	25.72	99.85	3.13	52.91
OY	33.25	5.74	90.02	20.49	36.97	42.27	76.50	22.15	66.62
LC	1.13	0.54	1.93	1.04	31.41	31.43	99.80	0.73	64.69
LY	6.46	0.91	15.53	16.98	42.27	45.52	86.11	5.22	80.81

CV = Coefficient of Variance; GCV = Genotypic covariance; PCV = Phenotypic covariance; h^2_{BS} = Heritability in broad sense in percent; GA = Genetic Advance, GAM = Genetic Advance as percent of mean. PH 30 DAT = plant height at 30 DAT (cm), PH 60 DAT = plant height at 60 DAT (cm), PH 90 DAT= plant height at 90 DAT (cm), SD = stem diameter (cm), NPB = number of primary branches per plant, NSB = number of secondary branches per plant, DBI = days to bud initiation, DFFO = days to first flower opening, FL= flower length (cm), FD = flower diameter (cm), NPF = number of petals per flower, NFP= number of flower pickings, NFP = number of flowers per plant, FWF = fresh flower weight (g), FYPP = flower yield per plant (kg), FYP = flower yield per plot (kg), FYH = flower yield per hectare (q), FPY= fresh petal yield per hectare (q), DPY = dry petal yield per hectare, OC = oleoresin content (q), OY = oleoresin yield (kg), LC = lutein content (%), LY = lutein yield (kg).

Flower quality is a multidimensional goal in marigold breeding, including size, shape, colour, aroma, and shelf life. Varieties with brilliant colours and uniform petal arrangements are more desired in the ornamental and religious markets [22]. Lutein content and lutein yield also varied significantly among genotypes (Table 3, Fig.1b-c). Higher lutein concentration and yield were observed in M-4, M-5, M-7, M-8, M-9, M-10, M-14, M-15, M-16, M-23, M-24, M-26, M-27, and M-29, compared with M-13 (Pusa Narangi). These genotypes, therefore, represent promising material for improvement targeting lutein content and lutein production. The variation in lutein content may be attributed to differences in the genetic makeup of the genotypes. Similar findings also reported in marigold for biochemical attributes by previous co-workers [17, 16, 1, 15]. The high values of both GCV and PCV were recorded for lutein yield (42.27% and 45.52%), lutein content (31.41% and 31.43%), oleoresin yield (36.97% and 42.27%), fresh flower weight (36.16% and 38.60%), number of primary branches per plant (31.96% and 39.21%), flower yield per plant (32.14% and 37.82%), flower yield per plot (32.16% and 37.83%), flower yield per hectare (32.15% and 37.83%), fresh petal yield (32.15% and 37.83%), dry petal yield (32.14% and 37.83%)(Table 4). The GCV and PCV for these variables exhibited comparatively substantial variance among accessions, implying that there is substantial scope for genetic improvement through selection [36, 1, 15].

The broad-sense heritability and genetic advance were high estimated for plant height at 90 DAT (85.27%, 26.46%), flower diameter (89.04%, 24.20%), number of petals per flower (97.69%, 62.75%), fresh flower weight (87.75%, 69.80%), oleoresin content (99.85%, 52.91%), lutein content (99.80%, 64.69%), and lutein yield (86.11%, 80.81%) (Table 4). Apart from heritability in the broad sense (h^2b), genetic advance influences the efficacy of selection and may serve as an effective selection criterion for significant economic traits. Several studies have supported these findings [14, 36, 38, 2]. The studies showed that genetically diverse genotypes should be exploited as donor parents in breeding programmes for the improvement of varieties/hybrids with a broad genetic base [36].

In the correlation matrix (Fig. 2), positive correlations are indicated by blue shading and negative correlations by red shading, as shown in the colour scale. The intensity of shading represents the strength of correlation, while blank cells denote non-significant associations at the 5% probability level. The correlation coefficients among the assessed traits revealed a significant

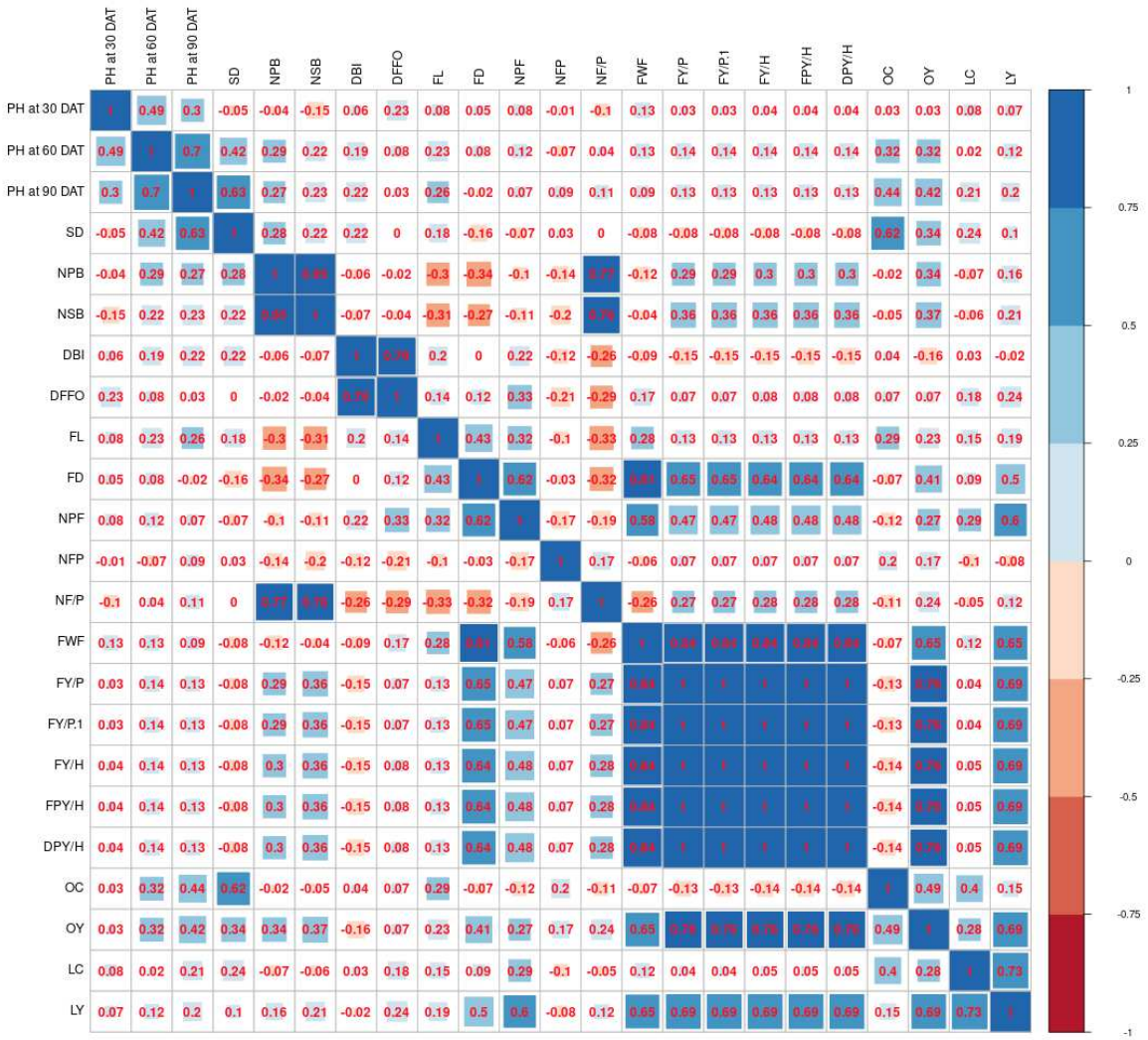


Figure 2. Correlogram from the 23 traits pooled mean values.

299 **Table 5 Genotypic path analysis with dependent variable**

Traits	PH 30 DAT	PH 60 DAT	PH 90 DAT	SD	NPB	NSB	DBI	DFFO	FL	FD	NPF	NFP	NF/P	FWF	FYP	FY/P	FYH	FYP	DYP	OC	OY	LC
PH 30 DAT	-0.437	-0.238	-0.142	0.034	0.007	0.062	-0.031	-0.113	-0.024	-0.025	-0.036	0.026	0.039	-0.059	-0.022	-0.022	-0.022	-0.022	-0.022	-0.011	0.016	-0.036
PH 60 DAT	0.210	**0.386**	0.284	0.229	0.128	0.094	0.081	0.033	0.092	0.031	0.047	-0.062	0.009	0.055	0.057	0.057	0.057	0.057	0.057	0.127	0130.	0.007
PH 90 DAT	-0.048	-0.110	**-0.150**	-0.135	-0.044	-0.035	-0.037	-0.005	-0.049	0.002	-0.010	-0.021	-0.017	-0.014	-0.020	-0.020	-0.020	-0.020	-0.020	-0.067	0.065	0.032
SD	0.005	-0.037	-0.057	**-0.063**	-.032	-0.025	-0.021	0.004	-0.017	0.016	0.006	-0.006	-0.002	0.006	0.006	0.006	0.006	0.006	0.006	-0.057	0.033	0.022
NPB	-0.007	0.159	0.141	0.242	**0.481**	0.466	-0.034	-0.008	-0.173	-0.177	-0.054	-0.108	0.407	-0.062	0.146	0.146	0.146	0.146	0.146	-0.011	0.166	-0.034
NSB	0.090	-0.156	-0.151	-0.256	-0.618	**-0.638**	0.051	0.033	0.217	0.187	0.078	0.249	-0.530	0.031	-0.238	-0.238	-0.238	-0.238	-0.238	0.030	-0.245	0.037
DBI	-0.013	-0.037	-0.044	-0.059	0.012	0.014	**-0.178**	-0.143	-0.042	0.000	-0.043	0.031	0.054	0.017	0.029	0.029	0.029	0.029	0.029	-0.008	0.031	-0.005
DFFO	0.103	0.034	0.015	-0.025	-0.006	-0.020	0.319	**0.398**	0.055	0.053	0.142	-0.142	-0.127	0.074	0.039	0.039	0.039	0.039	0.039	0.027	0.035	0.075
FL	0.007	0.033	0.045	0.037	-0.049	-0.047	0.033	0.019	**0.135**	0.066	0.048	-0.020	-0.050	0.042	0.021	0.021	0.021	0.021	0.021	0.044	0.037	0.021
FD	-0.019	-0.028	0.005	0.087	0.127	0.101	0.001	-0.046	-0.166	**-0.345**	-0.217	0.014	0.123	-0.288	-0.232	-0.232	-0.232	-0.232	-0.232	0.024	-0.148	-0.029
NPF	0.002	0.004	0.002	-003	-0.003	-0.004	0.008	0.012	0.012	0.021	**0.034**	-0.010	-0.007	0.020	0.017	0.017	0.017	0.017	0.017	-0.004	0.009	0.009
NFP	-0.000	-0.002	0.002	0.001	-0.003	-0.005	-0.002	-0.005	-0.002	-0.000	-004	**0.014**	0.004	-0.000	0.002	0.002	0.002	0.002	0.002	0.004	0.004	-0.002
NF/P	-0.087	0.024	0.113	0.034	0.823	0.809	-0.299	-0.311	-0.355	-0.348	-0.201	0.268	**0.974**	-0.279	0.213	0.213	0.213	0.213	0.213	-0.114	0.171	-0.048
FWF	0.261	0.274	0.187	-.201	-0.245	-0.092	-0.184	0.359	0.581	1.597	1.121	-0.091	-0.547	**1.910**	1.635	1.635	1.635	1.635	1.635	-0.133	1.258	0.233
FYP	1.852	5.448	4.861	-3.555	11.054	13.552	-6.037	3.585	5.714	24.523	18.287	5.414	7.951	31.129	**36.352**	36.352	36.352	36.352	36.352	-5.404	26.959	1.793
FY/P	2.655	7.845	6.987	-5.094	15.928	19.524	-8.690	5.144	8.199	35.279	26.307	7.789	11.458	44.785	52.312	**52.312**	52.312	52.312	52.312	-7.789	38.791	2.547
FYH	4.695	13.86	12.354	-9.01	28.155	35.506	-15.360	9.093	14.507	62.350	46.488	13.748	20.263	79.135	92.441	92.441	**92.441**	92.441	92.441	-13.767	68.547	4.499
FYP	0.266	0.787	0.701	-0511	1.598	1.959	-0.872	0.516	0.823	3.539	2.639	0.780	1.150	4.492	5.248	5.248	5.248	**5.248**	5.248	-0.781	3.891	0.255
DYP	-9.484	-28.04	-24.97	18.257	-56.960	-69.798	31.130	-18.374	-29.320	-126.096	-94.03	-27.805	-40.95	-160.090	186.985	186.985	186.985	186.985	**186.985**	27.831	-138.675	-9.075
OC	0.004	0.045	0.072	0.147	-0.003	-0.007	0.007	0.011	0.052	-0.011	-0.018	0.050	-0.019	-0.011	-0.024	-0.024	-0.024	-0.024	-0.024	**0.163**	0.083	0.065
OY	-0.015	-0.134	-0.172	-0.209	-0.137	-0.152	0.069	-0.035	-0.106	-0.170	-0.113	-0.122	-0.070	-0.261	-0.294	-0.294	-0.294	-0.294	-0.294	-0.203	**-0.397**	-0.116
LC	0.049	0.012	0.128	0.214	-0.043	-0.034	0.018	0.113	0.094	0.051	0.172	-0.097	-0.029	0.073	0.029	0.029	0.029	0.029	0.029	0.241	0.175	**0.598**
LY	0.088	0.138	0.210	0.157	0.168	0.225	-0.028	0.280	0.232	0.548	0.640	-0.098	0.077	0.705	0.737	0.736	0.736	0.736	0.736	0.140	0.714	0.742

300 **RESIDUE = - 0.1631**

and positive association between lutein yield dry petal yield (r = 0.69**), fresh petal yield (r = 0.69**), flower yield per hectare (r = 0.69**), flower yield per plot (r = 0.69**), flower yield per plant (r = 0.69**), oleoresin yield (r = 0.69**), lutein content (r = 0.73**), fresh flower weight (r = 0.65**), and number of petals per flower (r = 0.60**), respectively. These traits should be more useful in selection programmes. In contrast, correlations of lutein yield with days to first flower opening (r = 0.24, NS), number of secondary branches per plant (r = 0.21, NS), flower length (r = 0.19, NS), number of primary branches per plant (r = 0.16, NS), oleoresin content (r = 0.15, NS), and number of flowers per plant (r = 0.12, NS) were non-significant. If the correlation is positive and significant, the desirable traits facilitate their simultaneous improvement, likely to be accompanied by increases in one of their characters. [37, 8, 2].

Path analysis in the present study for direct and indirect contributions towards total lutein yield is presented in Table 5. The traits, *viz.,* fresh yield of petals (5.245), flower yield per hectare (92.441), flower yield per plot (52.312), flower yield per plant (36.352), fresh weight of flower (1.910), number of flowers per plant (0.974), and lutein content (0.598) had highly positive direct effects on Lutein yield (0.742). A genotypic path coefficient study with a dependent variable delineates the direct and indirect influences of other variables by breaking down the correlation coefficient into its components [37]. It suggested that these traits were important for improvement in lutein yield, which can be achieved through selection based on these traits. Several studies supported these findings [39, 1, 2, 11, and 12].

Principal component analysis (PCA) is used to explain the relationships among different groups of traits and the associations between genotypes. All traits also showed a high degree of variation according to the principal component analysis, cumulative percentage of variation, and eigenvalue (Table 6). In the present investigation, the first eight principal components accounted for 94.43% of the total variation (Table 6). PC1 described 35.777% of the total variation, with the highest eigenvalue of 8.229, and presented a desirable association with FWF, FYPP, FY/P, FYH, FYP, DPY, and LY. PC2 has an eigenvalue of 3.755 and explains 16.327% of the variation, and the traits that contributed were PH 90 DAT, SD, PH 60 DAT, OC, and OY. PC3 explained 15.639% of the variation, mainly due to NF/P, FD, NPB, and NSB. PC4 accounted for 9.988 of the variation and was primarily influenced by DFFO, NFP, DBI, NPB, and NSB. LC and LY had the highest loading in PC5, while PH 30 DAT and DBI dominated in the sixth principal component (PC6), highlighting their importance. Yield-attributing traits and lutein

Table 6 Eigen value percentage of variance, cumulative percentage of variance, and principle components for economic traits in *Tagetus erecta* L.

Traits	PC1	PC2	PC3	PC4	PC5	PC6	PC7	PC8
PH 30 DAT	0.900	0.970	2.062	7.024	16.293	20.538	9.231	3.645
PH 60 DAT	0.050	13.295	0.533	0.515	9.265	10.501	0.839	22.388
PH 90 DAT	0.337	20.032	0.000	0.885	5.843	0.049	0.279	5.290
SD	0.634	17.269	1.336	0.028	4.535	0.169	0.134	6.028
NPB	1.336	0.004	15.318	11.654	2.161	0.032	1.331	0.105
NSB	2.930	0.134	13.005	10.093	2.765	0.079	0.589	0.000
DBI	3.357	0.533	3.246	13.257	0.045	18.654	0.723	2.037
DFFO	1.228	0.052	2.728	19.685	0.670	10.313	14.699	8.834
FL	0.002	4.201	6.499	0.289	1.672	0.068	37.687	26.56
FD	3.647	0.031	15.403	0.622	0.431	0.099	0.026	0.004
NPF	1.711	0.408	9.843	4.772	5.046	3.133	7.125	15.671
NFP	0.766	0.026	4.021	17.395	4.407	15.888	3.058	1.883
NFP	1.801	0.426	18.551	1.137	0.800	1.217	5.913	0.450
FWF	8.544	0.295	5.166	1.580	0.445	0.188	2.542	0.009
FYPP	11.838	0.000	0.005	0.142	0.124	1.156	0.270	0.386
FY/P	11.847	0.001	0.000	0.181	0.073	1.165	0.145	0.504
FYH	11.844	0.001	0.000	0.185	0.074	1.170	0.150	0.517
FYP	11.844	0.001	0.000	0.185	0.074	1.170	0.150	0.517
DPY	11.847	0.001	0.000	0.184	0.074	1.156	0.152	0.509
OC	2.040	17.245	0.874	0.925	0.350	0.346	8.745	2.097
OY	5.396	10.111	1.227	1.240	0.139	0.035	6.174	1.712
LC	0.032	9.715	0.011	4.816	28.481	11.718	0.026	0.830
LY	6.067	5.243	0.172	3.205	16.231	1.156	0.011	0.024
Eigenvalue	8.229	3.755	3.597	2.297	1.256	1.076	0.959	0.550
Variability (%)	35.777	16.327	15.639	9.988	5.463	4.680	4.168	2.392
Cumulative variation (%)	35.777	52.104	67.743	77.731	83.193	87.874	92.042	94.433

PH 30 DAT = plant height at 30 DAT (cm), PH 60 DAT = plant height at 60 DAT (cm), PH 90 DAT= plant height at 90 DAT (cm), SD = stem diameter (cm), NPB = number of primary branches per plant, NSB = number of secondary branches per plant, DBI = days to bud initiation, DFFO = days to first flower opening, FL= flower length (cm), FD = flower diameter (cm), NPF = number of petals per flower, NFP= number of flower pickings, NFP = number of flowers per plant, FWF = fresh flower weight (g), FYPP = flower yield per plant (kg), FYP = flower yield per plot (kg), FYH = flower yield per hectare (q), FPY= fresh petal yield per hectare (q), DPY = dry petal yield per hectare, OC = oleoresin content (q), OY = oleoresin yield (kg), LC = lutein content (%), LY = lutein yield (kg).

yield were mainly represented by PC1 and PC2, while PC5 mainly encompassed biochemical traits and exhibited their contribution to phenotypic variation.

The scores of the eight major components of the twenty-three genotypes, sorted from high to low, suggest the key choice of important agro-biochemical traits like flower yield and lutein yield. In addition, the first eight components account for 94.43% of the total variation, which may be due to the low correlation among agro-biochemical traits, but each principal component has an eigenvalue >1. This significant percentage reflects the strength of these components in capturing genetic variation within the selected population. This finding emphasizes the usefulness of PCA in simplifying complicated datasets and evaluating critical variables for genetic and biochemical studies. Breeders can more easily select a small sample of a very distinct gene pool using PCA data for further genotype testing [42-43]. The study found that selecting high-quality genetic materials is important for breeding activities. PCA technique was used to study the genetic relationships among the marigold genotypes [40].

The PCA biplot revealed the multivariate relationships among the studied traits and genotypes based on Principal component scores and trait loadings (Fig.3). The first two principal components, Dim1 (37.1%) and Dim2 (15.6%), together accounted for 52.7% of the total variation, indicating that those two dimensions adequately showed the substantial proportion of the variability present in the germplasm. The positive correlation of DPYH, OY, NPB, and NSB with Dim 2 and their close positioning with genotypes M-1 and M-20 indicated that these genotypes possess favourable combinations of traits related to productivity and yield components. Thus, M-1 and M-20 may be considered promising genotypes for further evaluation and utilization in crop improvement. In contrast, M-7 and M-10 were positioned in the bottom-right quadrant and showed close association with FY.P, FWF, and LY, suggesting that these genotypes differ from M-1 and M-20 in their contribution to the major yield-contributing traits. The positioning of M-22 close to the origin indicated that it had relatively moderate or average values for the traits represented by the first two principal components and was not strongly associated with any particular traits. The close association with Dim1 further suggests that this component was strongly influenced by variation in traits. Overall, the PCA clearly differentiated the genotypes according to their multivariate trait profiles and identified M-1 and M-20 as closely related genotypes with desirable agro-biochemical traits. Similar usefulness of PCA for

identifying genotype– trait associations and discrimination of promising genotypes has also been reported by [41, 21, 2].

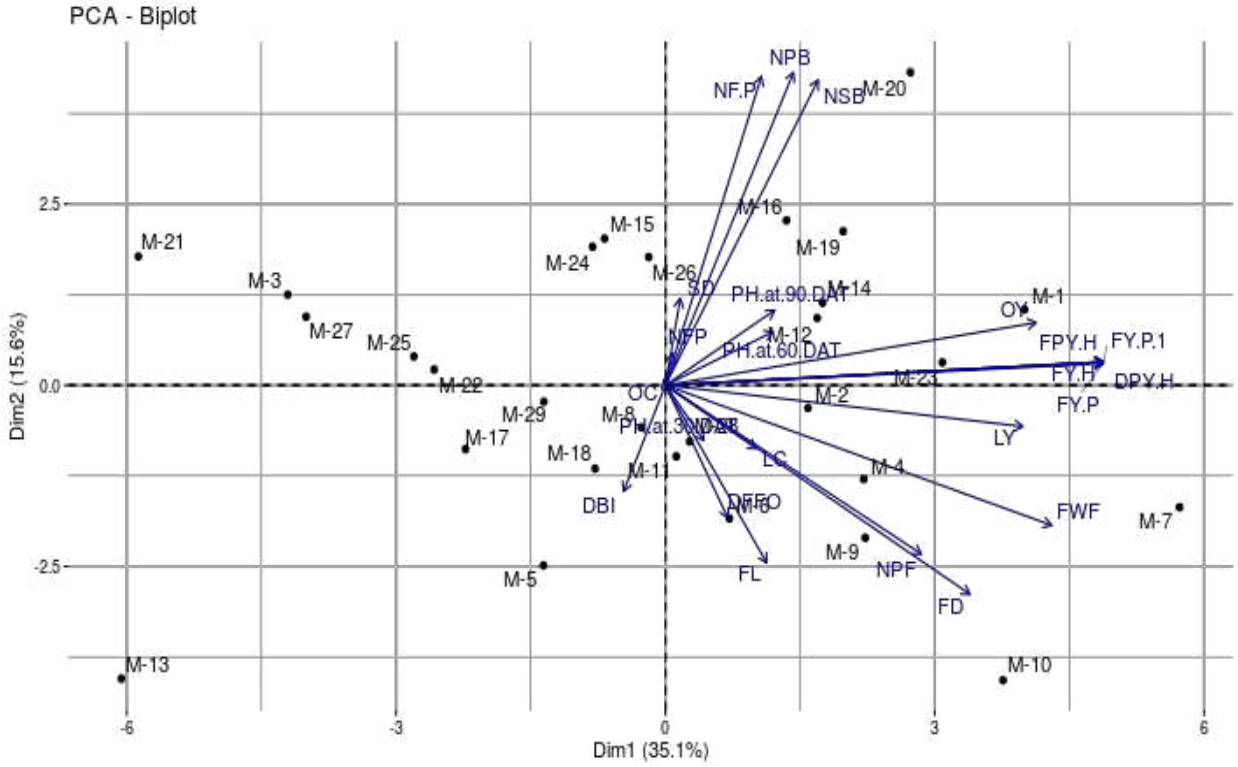


Figure 3. PCA biplot of twenty nine genotypes of *Tagetes erecta* and twenty three quantitative and qualitative traits.

PCA analysis was performed on the analysed traits (dependent variables) to assess the extent of multivariate variation and to identify the traits contributing most strongly to the differentiation among marigold genotypes. The first two principle components (Dim 1 and Dim 2) together explained 54.1% of the total variation, indicating that a substantial proportion of the variability among the genotypes could be represented in the two-dimensional PCA values (Fig.4). Among the studies variables, OC, LY OY and FWF showed strong distributions, suggesting that these traits were important contributions to the major source of variation among the marigold genotypes. In contrast, traits such as NPB, DFFO and NPF showed relatively low contributions to the first two dimensions, suggesting that their variation was not adequately captured by the Dim1–Dim2 plane and that they had a comparatively smaller influence on the major multivariate pattern. Their strong contribution suggests that they may be widely useful for identifying promising materials based on yield and related traits [2, 21].

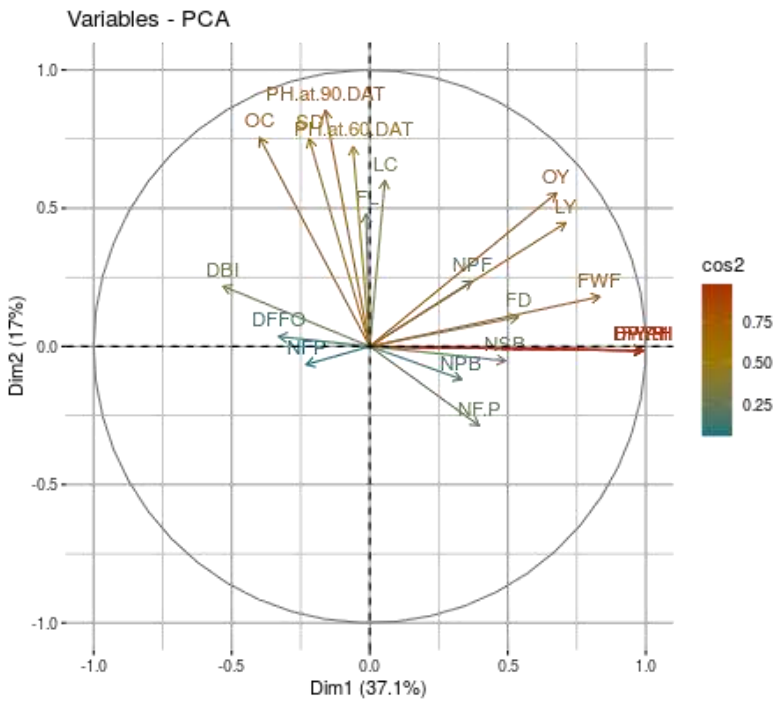


Figure 4. Contribution of different variables towards principal component analysis based on cos2 value.

The Scree plot illustrated the eigenvalues and proportion of total variance explained by successive principal components in the 29 marigold genotypes (Fig.5). The PCA results indicated that the first five principal components accounted for a substantial proportion of the total variability present in the dataset. PC1 explained the highest proportion of variation (37.1%), followed by PC2 (17%), PC3 (16.1%), PC4 (9.9%), and PC5 (5.4%). Collectively, these PCs accounted for 85.50% of the total variation among the genotypes, demonstrating that most of the variability associated with the agro-biochemical traits could be effectively shown by these components. The presence of eigenvalues >1.0 for the first five PCs further supported their retention for interpretation, as these components represented a meaningful source of variation, whereas the subsequent PCs contributed relatively smaller proportions of the total variability. The strong positive association of PC1 with flower yield and lutein yield indicated that these traits were major contributors to the overall variability observed among the marigold genotypes. This suggests that PC1 primarily represented a productivity-related dimension and could therefore be particularly useful for differentiating genotypes based on flower yield and lutein productivity. The PCA provides useful information for identifying important traits and differentiating genetically diverse marigold genotypes, which can assist in the selection of superior parents and the formulation of effective breeding strategies for simultaneous

improvement of yield and quality traits. Similar results were also reported by earlier co-workers [41, 21, 2].

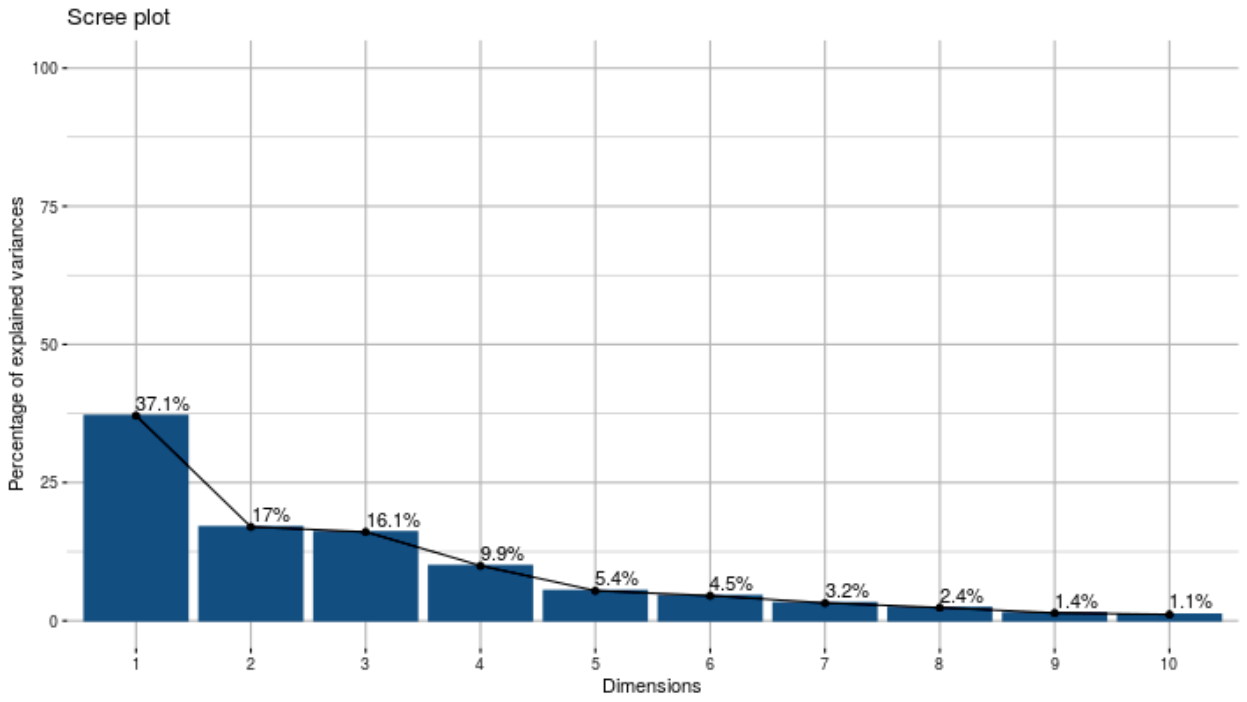


Figure 5. Screen plot based on eigenvalues depicting the percentage of variation explained by each principal components.

The 29 marigold genotypes were clearly separated into two major groups by the cluster dendrogram (Fig. 6). Cell colors represent standardized trait values according to the gradient scale (right): dark purple (0-50) showed low values, blue (50-150) showed moderate values, and yellow-green (300-400+) indicated high values. The vertical dendrogram (right) shows hierarchical clustering of genotypes based on overall phenotypic similarity, with pink/red and green/teal branches indicating major cluster groups. The horizontal dendrogram (top) shows hierarchical clustering of traits based on their correlation patterns across genotypes. In the dendrogram, Cluster I has 5 genotypes and Cluster II has 24 genotypes. Cluster I was further separated into two sub-clusters: Sub-cluster Ia, which had one genotype (M-10), and Sub-cluster Ib, which had four genotypes (M-7, M-19, M-4, M-12). Two sub-clusters, IIa and IIb, were also created from Cluster II, which had the most genotypes. There were 16 genotypes in Sub-cluster IIa and 8 in Sub-cluster IIb. Sub-cluster IIa was further divided into smaller sub-clusters. Closely clustered genotypes share similar multi-trait profiles, while distant genotypes represent phenotypically divergent germplasm. The evaluated germplasm included M-1 to M-29, a region-specific collection from farmers' field selections, representing a broad genetic base relevant for

marigold improvement. Genotype M-10 emerged as a distinctly superior line, exhibiting consistently high values across key yield and quality traits, including number of flowers, flower diameter, and lutein yield. Hierarchical clustering placed M-10 in a separate cluster, highlighting its unique phenotypic profile and genetic distinctiveness. This genotype, therefore, represents a valuable resource for breeding programmes targeting high flower yield and enhanced lutein production. Trait clustering revealed biologically meaningful associations among parameters. Plant height at different growth stages clustered together, reflecting coordinated vegetative growth, while flowering and yield-related traits formed distinct groups, indicating shared genetic regulation. Several genotypes, including M-7, M-12, and M-23, displayed intermediate to high performance for specific traits, suggesting their potential utility as parental lines. In contrast, comparatively lower performance of certain commercial cultivars across yield traits underscores the scope for genetic improvement through hybridisation with superior experimental genotypes.

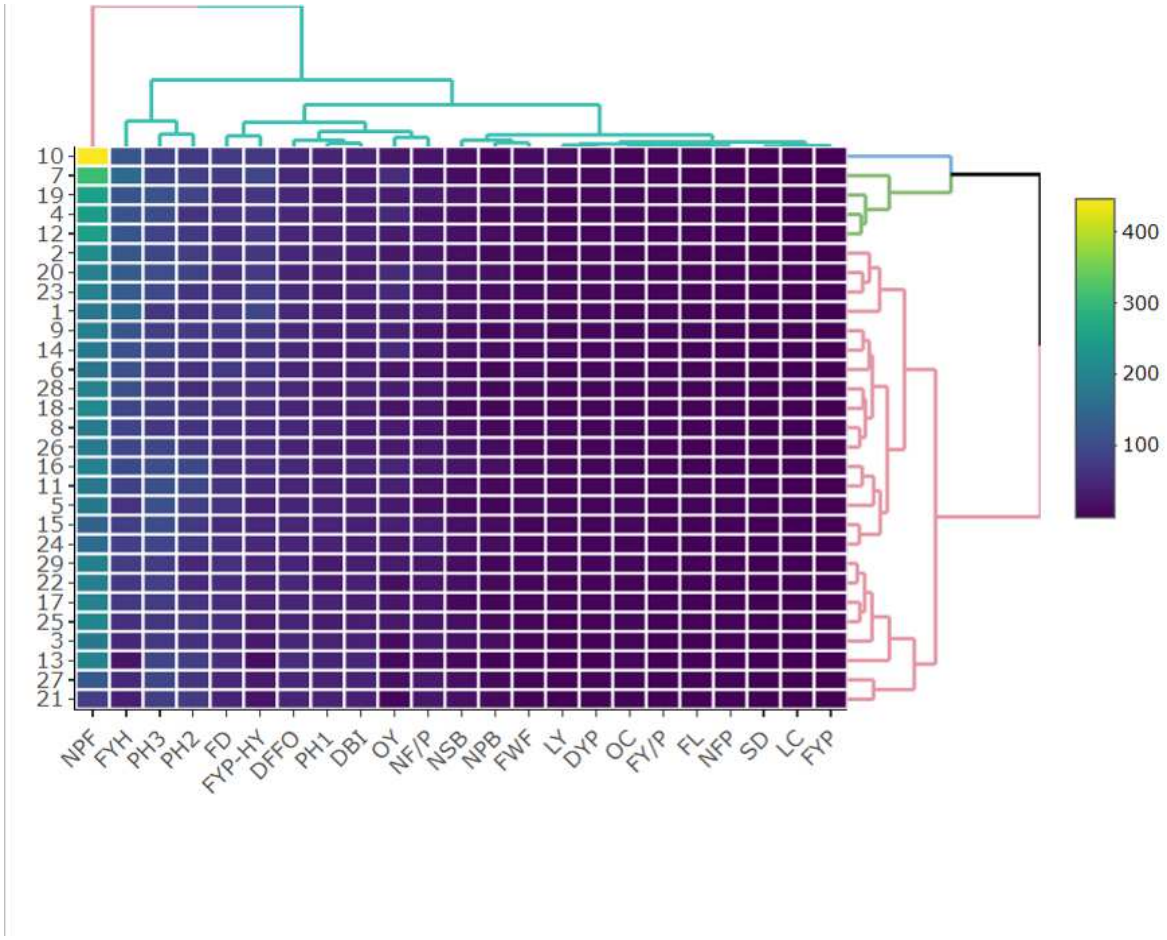


Figure 6. Heat map showing the correlation among twenty three quantitative and qualitative traits in *Tagetes erecta*.

The heat map clustering revealed a distinct grouping pattern between the marigold genotypes. Multivariate statistical analysis using heat maps provides a deeper understanding of the contribution of agro-biochemical traits to taxonomic classification [42-43]. Two-way heatmaps cluster analysis illustrated the patterns of agro-biochemical variability by simultaneously grouping both traits and genotypes (rows and columns), thereby revealing the contribution of different traits to the overall genetic variation among marigold genotypes. It effectively explores the relationship between genotypes and attributes, thereby assisting in understanding the genetic makeup of essential traits and strategically selecting diverse and compatible parents for breeding programs [42, 40, 43]. The Heat map dendrogram clusters two primary groups as Cluster I and II, which were subdivided into Ia, Ib, IIa, and IIb, representing groups of genotypes sharing similar agro-biochemical traits. These clustered traits indicated inherent associations governed by genetic components, irrespective of the geographical origin of the genotypes. Furthermore, genetic materials were classified based on similarities in agro-morphological characteristics rather than their geographical origin. Each cluster represents a distinct set of features and potential breeding value, allowing breeders to select and utilize the best genetic resources from various clusters based on specific breeding objectives [20]. The close grouping of genotypes within each cluster indicates their genetic relationship [42]. For instance, Cluster Ia grouped genotype M-10, which is significantly different from other cluster genotypes for agro-biochemical traits including number of flowers, flower diameter, and lutein yield. This genotype, therefore, represents a valuable resource for breeding programmes targeting high flower yield and enhancing lutein production.

The heat map illustrated the correlation between different traits and their respective principal components, providing major sources of variation among the marigold genotypes (Fig.7). PC1 showed strong positive correlation with FY.P (0.987), FY.P.1 (0.987), FY.H (0.987), FYP.H (0.987), DPY.H (0.987), FWF (0.838), OY (0.666) and LY (0.707), suggesting that this component predominantly represented a yield and productivity related dimension, with important implication for biochemical productivity. In contrast, DBI showed a negative association with PC1 (-0.526), indicating an inverse relationship with the traits contributing positively to this component. PC1 can be considered a useful selection criterion in marigold breeding programmes aimed at improving yield and associated biochemical traits. Genotypes possessing favourable scores for PC1 may be particularly valuable as potential parents for developing high-yielding and quality-oriented marigold varieties. Similar results were found by previous researchers [25, 20].

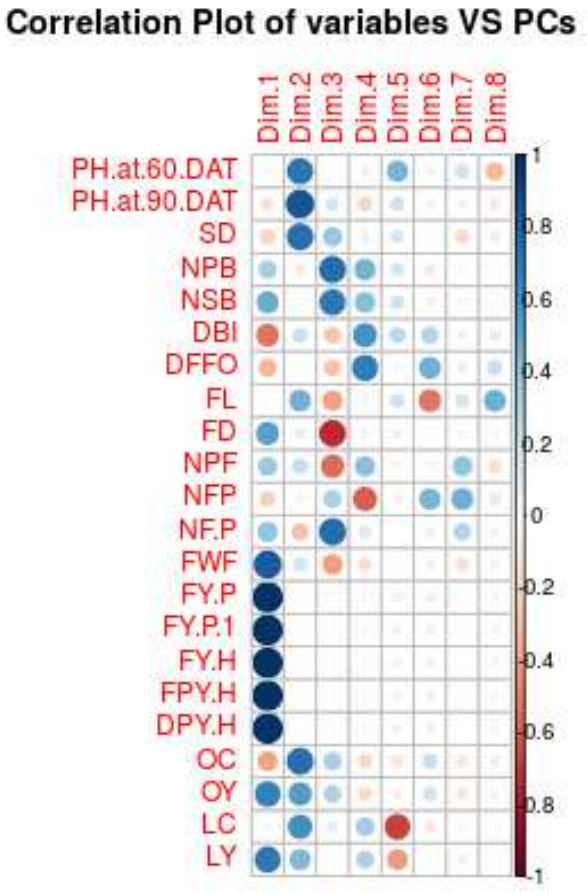


Figure 7. The heat map showed a correlation between PC and traits.

.The wide range of genetic variability found among marigold genotypes. This genetic diversity highlights the importance of conservation efforts in preserving valuable genetic resources. Breeders can generate superior varieties by combining phenotypic features with DNA-based molecular markers, increasing the quality of flower production and strengthening the application in the pharmaceutical industry. Combining phenotypic and genomic data can reveal evolutionary links and provide a deeper understanding of genetic resources in plants. Plant breeders might concentrate on traits that are consistent with pharmaceutical standards and valuable in the floral industry. Further breeding programs can be strengthened by integrating advanced molecular techniques, such as marker-assisted selection, to accelerate the development of cultivars with desirable traits.

Conclusion

The significant genetic variability observed in quantitative and qualitative traits among the marigold cultivars provides valuable opportunities for targeted genetic improvement. Genotypes such as M-4, M-5, M-7, M-8, M-9, M-10, M-14, M-15, M-16, M-23, M-24 and M-26 represent

promising donor sources for enhancing lutein content and lutein yield. Traits exhibiting high heritability coupled with high genetic advance, namely plant height at 90 DAT, flower diameter, number of petals per flower, fresh flower weight, oleoresin content, lutein content, and lutein yield, should be prioritised for effective selection in breeding programmes. The higher GCV and PCV were recorded for lutein recovery and yield, oleoresin yield, and number of flowers yield. This indicates that these traits are important lutein yield components, and the effective improvement in lutein yield can be achieved through selection based on these traits. Future efforts should focus on developing molecular markers linked to lutein biosynthesis, integrating metabolomics, and elucidating biosynthetic pathways to enable chemotype-specific marigold cultivars and improve the profitability of marigold cultivation.

Data Availability

Availability of data and materials: All data generated or analysed during this study are included in this manuscripts.

Declaration

Abbreviations: All abbreviations are defined upon first use in the manuscript.

Ethics approval and consent to participate: Not applicable.

Consent for publication: Not applicable.

Competing Interests: The authors declare that they have no conflict of interest.

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Authors contributions: Investigation, Conceptualization, Data curation, Manuscript writing, S. K. Y., R. M., and K. L., Software, Data analysis, Graph preparation, R. K. L., Visualization, Resources, Methodology, Formal analysis, Manuscript editing, Supervision, R. S. V., V. S., and R. K. V., Manuscript writing, S. M., and S. S. C. All authors have read and agreed to the published version of the manuscript.

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Figure's captions

Figure 1a-c. Mean performance of different economic traits a. flower yield (q/ha), b. lutein content (%), and c. lutein yield (Kg.ha) in the genotypes of *Tagetus erecta* L.

Figure 2. Correlogram from the 23 traits pooled mean values.

Figure 3. PCA biplot of twenty nine genotypes of *Tagetes erecta* and twenty three quantitative and qualitative traits.

Figure 4. Contribution of different variables towards principal component analysis based on cos2 value.

Figure 5. Screen plot based on eigenvalues depicting the percentage of variation explained by each principal components.

Figure 6. Heat map showing the correlation among twenty three quantitative and qualitative traits in *Tagetes erecta*.

Figure 7. The heat map showed a correlation between PC and traits.