



RESEARCH ARTICLE

The relationship between various weather parameters and their influence on the growth and flowering of African marigold under continuous transplanting conditions throughout the year

Rakesh Kumar*, Ranjit Singh & Kamal Kishore Nagar

Department of Floriculture and Landscaping, Punjab Agricultural University, Ludhiana 141 004, Punjab, India

*Correspondence email - rakesh.kajla06@gmail.com

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Abstract

Climate variability poses a significant threat to agricultural sustainability; consequently, practical solutions are necessary to increase agricultural production. Planting time is a crucial factor influencing the growth and flower production of marigold, particularly when cultivated throughout the year. This study aims to determine the optimal growth period for African marigold in North Indian subtropical plains, where it is cultivated as a year-round cash crop. The research employed a randomised complete block design (RCBD), with 12 transplanting dates for marigold implemented from February 15th to January 15th of each year. The findings revealed that vegetative parameters, specifically maximum plant spread and higher number of primary branches (PB), along with physiological and yield traits such as fresh flower weight (FW), chlorophyll SPAD index, carotenoid content (CR) and flower yield per square meter, were optimally higher when the crop was transplanted on August 15th, followed by July 15th. The yield of flowers per square meter was observed maximum in August 15th transplanting, which decreased by approximately 38 % and 44 % when crop was transplanted during July and September, respectively. For other planting dates, the mean reduction in flower yield per square meter ranged from 66 % in February to 82 % in December transplanted crops compared to August transplanting. Phenological stages, colour break stage and flowering duration occurred earlier in crops transplanted on October 15th. This study demonstrates that maximum plant growth development and flower production were observed when transplanting was done on July 15th and August 15th. The principal component analysis (PCA) biplot indicates clear associations between weather variables and plant growth and yield attributes. Plant height (PH), PB, FW and CR and SPAD value (SPD) show a positive correlation with sunshine hours (SUN) and maximum temperature (MXT) and a negative correlation with excessive rainfall, suggesting warm and spring seasons favour vegetative growth and pigment accumulation.

Keywords: climate variability; flower yield; marigold; transplanting dates

Introduction

The marigold (*Tagetes erecta* L.) is one of the most important commercial flower crop grown worldwide and especially for loose flower production as a cash crop in India, Pakistan, Bangladesh and Sri Lanka. For optimal growth and flowering, marigold requires a mild climate but high or low temperatures (18–30 °C) at reproductive stage may lead to stress due to various reasons that ultimately result in yield losses. As it is being grown throughout the year, the subtropical temperature variations over the year in terms of minimum and maximum temperature (MXT) along with other weather variables has significantly deeper impact on growth and flower yield thereby directly affecting the economic gains of the stakeholders. The crop has climatic and time requirements, which when not adhered to—alongside farmers' common lack of matching seasonal customary practices with appropriate weather conditions—tends to result in poor growth, delayed flowering timing, low yield and susceptibility to stress. These concerns should be specified to emphasise the problem and importance of the study.

Sometimes the inevitable climatic constraints such as frost, untimely rain and high humidity negatively affect the crops resulting in low yield or failure of crop. The sowing date is very important because it will define to which stage the crop will subject to these stress conditions. If sowing is early or delayed, crops could be exposed to heat stress at germination, low temperatures at flowering or excess water content during vegetative growth that results in poor crop establishment and retardation of phenology and a lower yield. Climatic barriers pose an adverse effect on crops, resulting in low yields or even crop failure (1). Under year round flower production regimes, as the weather clock moves through extreme cold, extreme summer, heavy rain fall with high humidity and comparatively mild climatic conditions of typical subtropics, development of plant growth, phenology and flower yield of marigold are significantly affected by climate change triggered variability which induce abiotic stress at various crop developmental stages leading potentially to cause pollen sterility, altering the flowering days and affecting days to crop maturity. Year-round flower

production systems in the crops like marigold is imperative because requirement of loose flowers are as continuous and season neutral, particularly for religious rituals, social function, decoration and market festivity. Standardised sowing windows to coincide sensitive stages of marigold with favourable weather condition has been worked out by different State Agriculture University (SAUs) and research institutes. These optimal sowing dates allow growers to avoid cold and high temperatures, reducing the risk of drought through which they exploit stable grain yield. Chlorophyll SPAD index is indirect indicator of plant health and photosynthetic activity which results in optimum growth and flower yield. Higher chlorophyll SPAD index values generally indicate improved photosynthetic efficiency, which can boost total plant productivity and flower yield which can be correlated with economic yields. The cultivar of African marigold, Punjab Gaiinda No. 1, released by Punjab Agricultural University, Ludhiana, India is grown on large scale throughout the year. The information on growth and yield is not available for loose flower production in relation to the prevailing climatic conditions when it is cultivated throughout the year as there is no systematic data on yield statistics. This experiment was conducted to assess the impact of year-round transplanting on the growth, flowering and yield attributes of African marigold cv. Punjab Gaiinda No. 1 as affected by weather variables. The objective of this experiment was to find out the optimum time for marigold transplanting in India's northern plains with aim to regulate and also to draw a correlation between weather variables and phenological stages contributing to changes in economic yields.

Materials and Methods

Field experiments were conducted in 2021–22 and 2022–23 at the Research Farm of the Department of Floriculture and Landscaping, Punjab Agricultural University (PAU), Ludhiana. The experiment was planned using a randomised complete block design (RCBD) with 12 planting dates and replicated thrice and the pooled data for the two years is presented. Climate variables data and soil parameters for the specified area are given in Table 1 and Fig. 1. The location of the research farm is at 30°54' N, 75°48' E, an altitude of 247 m above sea level. The Department of Climate Change and Agricultural Meteorology at the PAU, Ludhiana provided meteorological data for the crop growth period. From the beginning in January and continuing throughout the year, seeds were sown on raised nursery beds that were prepared by incorporating 5 kg of well-decomposed farmyard manure (FYM) per square metre. The seeds were sown in lines, spaced 2–3 cm apart and covered with finely sieved leaf mold. The seedlings were transplanted to the main field monthly after they achieved a transplantable height of 7–10 cm. In order to prepare the transplanting beds, 10–15 kg of well-decomposed FYM were mixed with each bed as per recommendations of cultivation practices formulated by PAU (2) along with recommended a basal dose of fertiliser were calculated viz, urea (320 kg acre⁻¹), single superphosphate (250 kg acre⁻¹) and muriate of potash (66 kg acre⁻¹) were applied. Plot size were kept 2.40 × 2.40 m and planting distance of 40 × 40 cm was followed while transplanting in the main field and ten healthy randomly plants were selected at the 7–10 cm height for data collection. Data were recorded on various

Table 1. Physical and chemical properties of soil

Sl.No.	Physical properties of soil	Value
Particle size analysis		
1.	Sand (%)	72.8
2.	Silt (%)	14.9
3.	Clay (%)	16.6
	Texture class	Sandy loam
1.	Bulk density (g cc ⁻¹)	1.58
2.	Particle density (g cc ⁻¹)	2.71
3.	Porosity (%)	41.98
Chemical properties		
1.	Soil pH (1:2 soil : water suspension)	7.87
2.	Electrical conductivity (ds m ⁻¹ at 25°C in 1:2 soil : water suspension)	0.50
3.	Organic carbon (%)	0.41
4.	Nitrogen (kg ha ⁻¹)	200.5
5.	Phosphorus (kg ha ⁻¹)	31.8
6.	Potassium (kg ha ⁻¹)	270.7

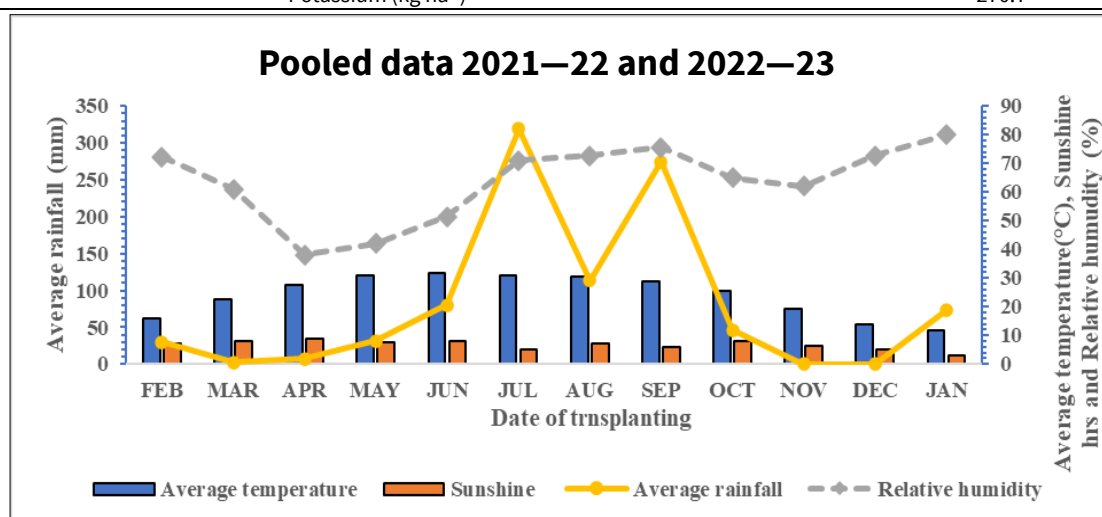


Fig. 1. Year-round mean monthly meteorological data during 2021–22 and 2022–23 (pooled).

growth parameters stages viz., plant height (PH) (cm) and plant spread (cm) at flower bud appearance, number of primary branches per plant (PB), bud diameter (BD) (cm), bud length (BL) (cm), days to colour break stage and duration of flowering. Yield attributes parameters were recorded at full flower opening of flower yield m^{-2} , carotenoids content (mg g^{-1}) and chlorophyll SPAD index were recorded with the help of SPAD photometer (SIM biochem SPAD meter) when plants reached flowering stage. R software version 2.2.0 was used to do an analysis of variance (ANOVA) on the data. R Software (2.2.0.) programme software was used for correlation analysis.

Determination of carotenoids content (mg g^{-1})

Fresh sample of flower was collected from the plants and 0.1 g samples were weighed from each sample. The samples were then crushed with pestle and mortar in 5 mL of 80 % acetone and the homogenate was filtered. The crushed samples were placed in test tubes and centrifuged at 2500 rpm for 10 min. The supernatant was collected in another test tube and the volume was made up to 10 mL using 80 % acetone. The absorbance of the final supernatant was recorded at 480 nm, 645 nm and 663 nm using a spectrophotometer (spectrophotometer model 6850).

The carotenoid content (CR) was determined using the following formula:

$$\text{Carotenoid} = A_{480} + 0.114 A_{665} - 0.638 A_{645} \times \left(\frac{V}{1000} \right) \times 100$$

Where,

A_{480} = Absorbance at 480 nm

A_{665} = Absorbance at 665 nm

A_{645} = Absorbance at 645 nm

V = Total volume of extract (mL)

W = Weight of the sample (g)

The value of carotenoid was expressed as mg g^{-1} fresh weight.

Results

Plant growth parameters

The pooled data of the year-round mean monthly meteorological data during 2021–22 and 2022–23 (Fig. 1) were collected to study the effect of various weather parameters on the growth and flowering of African marigold in different transplanting condition.

Mean PH recorded at first flower bud appearance was found maximum (69.83 cm) in 15th June transplanting followed by 15th July transplanting (Fig. 2) while the mean plant spread at the same stage of plant growth was recorded maximum (40.20 cm)

(Fig. 3) in 15th August transplanting followed by 15th July transplanting, however, minimum plant spread at this stage was recorded in 15th December transplanting. The maximum (1.0 cm) flower BD and BL (1.25 cm) was recorded on 15th August transplanting which is statistically at par with 15th July transplanting. Minimum (0.8 cm) flower bud diameter and length (0.80 cm) were observed on 15th December transplanting. Fig. 4 shows that from 15th October to 15th January transplanting dates, bud diameter has decreased progressively.

The PB recorded per plant at flower bud appearance are significantly affected with transplanting dates (Fig. 5). It is observed that maximum (5.40) PB per plant was exhibited on 15th August transplanting and minimum (1.60) on 15th December transplanting which were at par on 15th November. Longer duration (54.91 days) of flowering was noted on 15th August transplanting followed by 15th July transplanting whereas, on 15th June transplanting the flower duration was shortest and is statistically at par with 15th May transplanting.

Floral parameters

Floral parameters, particularly days to colour break, were also influenced significantly with the transplanting dates (Table 2). It was noted maximum (101.9 days) on 15th December transplanting which was found statistically at par with 15th November transplanting, whereas, minimum (60.3 days) number of days to colour break stage was recorded on 15th October transplanting and it was statistically at par with September transplanting. The duration of flower production was longest (54.91 days) on 15th August transplanting followed by 15th July transplanting. Treatments on 15th June transplanting and 15th May transplanting dates exhibited least flower production duration.

Yield and yield attributes

The flower weight (FW) and chlorophyll SPAD index value was recorded significantly higher (8.2 g and 54.84) on 15th August transplanting (Fig. 6) over all the other treatments under consideration. The maximum flower yield (2465.59 g m^{-2}) was recorded on 15th August transplanting followed by 15th July transplanting (1521.42 g m^{-2}) which is statistically at par with 15th September transplanting whereas, the flower yield was recorded lowest (181.88 g m^{-2}) in 15th December transplanting, 15th November and 15th January transplanting (Fig. 7). The total carotenoids content of flowers fluctuated with different treatments as maximum (1.11 mg g^{-1}) in 15th July (Fig. 8) transplanting, followed by 15th March and 15th August transplanting, while in other treatments total carotenoids were

Table 2. Effect of year-round transplanting on phenological stages in African marigold cv. Punjab Gaiinda No. 1. Main values in each column with the same letter are not significantly different at $p < 0.05$ according to Duncan's multiple range test (DMRT)

Phenological stages of African marigold			
Treatments	Days to visible flower bud	Days to colour break stage	Duration of flowering
15 th -February	54.62 $\pm$ 0.87 ^{cde}	66.8 $\pm$ 0.58 ^{de}	46.42 $\pm$ 0.79 ^c
15 th -March	57.09 $\pm$ 1.16 ^{cd}	69.2 $\pm$ 0.38 ^{cd}	41.13 $\pm$ 0.47 ^{ef}
15 th -April	59.26 $\pm$ 1.26 ^c	70.7 $\pm$ 0.50 ^{cd}	39.06 $\pm$ 0.43 ^f
15 th - May	66.16 $\pm$ 1.64 ^b	76.6 $\pm$ 0.70 ^{bc}	35.11 $\pm$ 0.54 ^g
15 th - June	71.01 $\pm$ 0.83 ^b	82.8 $\pm$ 1.04 ^b	33.87 $\pm$ 0.27 ^g
15 th - July	65.35 $\pm$ 1.37 ^b	76.8 $\pm$ 1.81 ^{bc}	49.90 $\pm$ 0.99 ^b
15 th - August	66.73 $\pm$ 0.69 ^b	79.1 $\pm$ 0.14 ^b	54.91 $\pm$ 0.62 ^a
15 th -September	51.90 $\pm$ 1.12 ^{de}	63.6 $\pm$ 0.55 ^{de}	43.26 $\pm$ 0.93 ^{de}
15 th -October	50.26 $\pm$ 1.11 ^e	60.3 $\pm$ 0.41 ^e	39.64 $\pm$ 0.87 ^f
15 th -November	82.45 $\pm$ 2.37 ^a	99.4 $\pm$ 1.11 ^a	38.84 $\pm$ 0.77 ^f
15 th -December	84.52 $\pm$ 1.31 ^a	101.9 $\pm$ 0.92 ^a	45.89 $\pm$ 0.42 ^{cd}
15 th -January	69.52 $\pm$ 1.32 ^b	82.8 $\pm$ 0.82 ^b	45.92 $\pm$ 0.44 ^{cd}

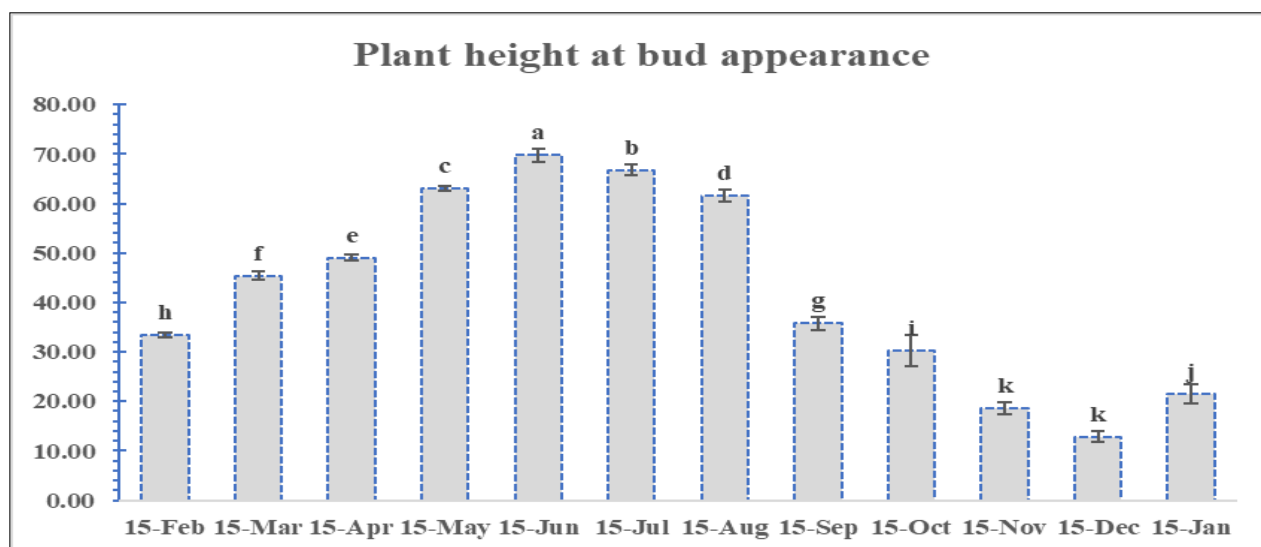


Fig. 2. Effect of year-round transplanting on plant height (cm) at flower bud appearance in African marigold cv. Punjab Gaiinda No. 1. Main values in each bar diagram with the same letter are not significantly different at $p < 0.05$ according to Duncan's multiple range test (DMRT).

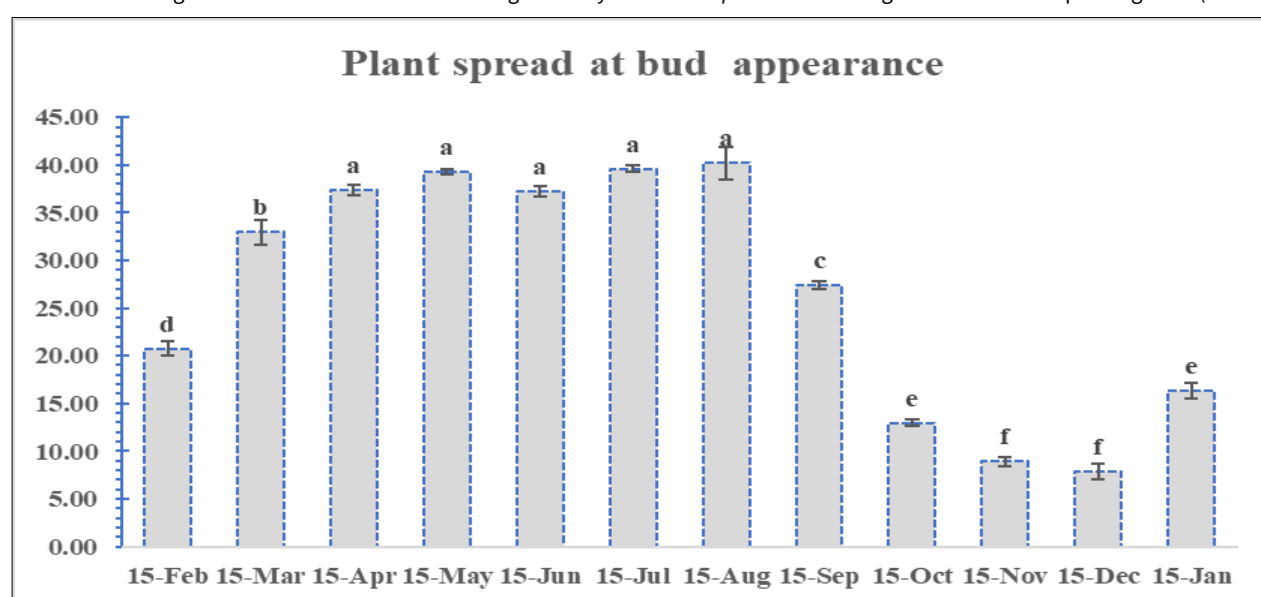


Fig. 3. Effect of year-round transplanting on plant spread (cm) at flower bud appearance in African marigold cv. Punjab Gaiinda No. 1. Main values in each bar diagram with the same letter are not significant different at $p < 0.05$ according to Duncan's multiple range test (DMRT).

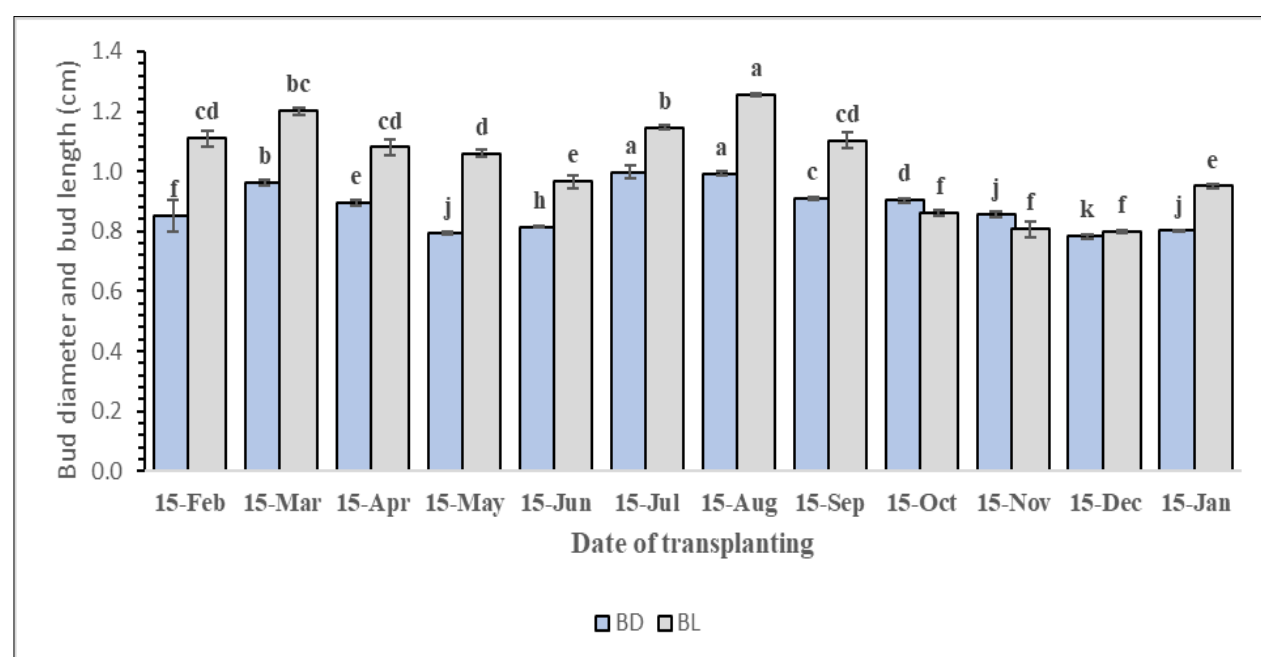


Fig. 4. Effect of year-round transplanting on bud diameter (BD) and bud length (BL) (cm) in African marigold cv. Punjab Gaiinda No. 1. Main values in each bar diagram with the same letter are not significantly different at $p < 0.05$ according to Duncan's multiple range test (DMRT).

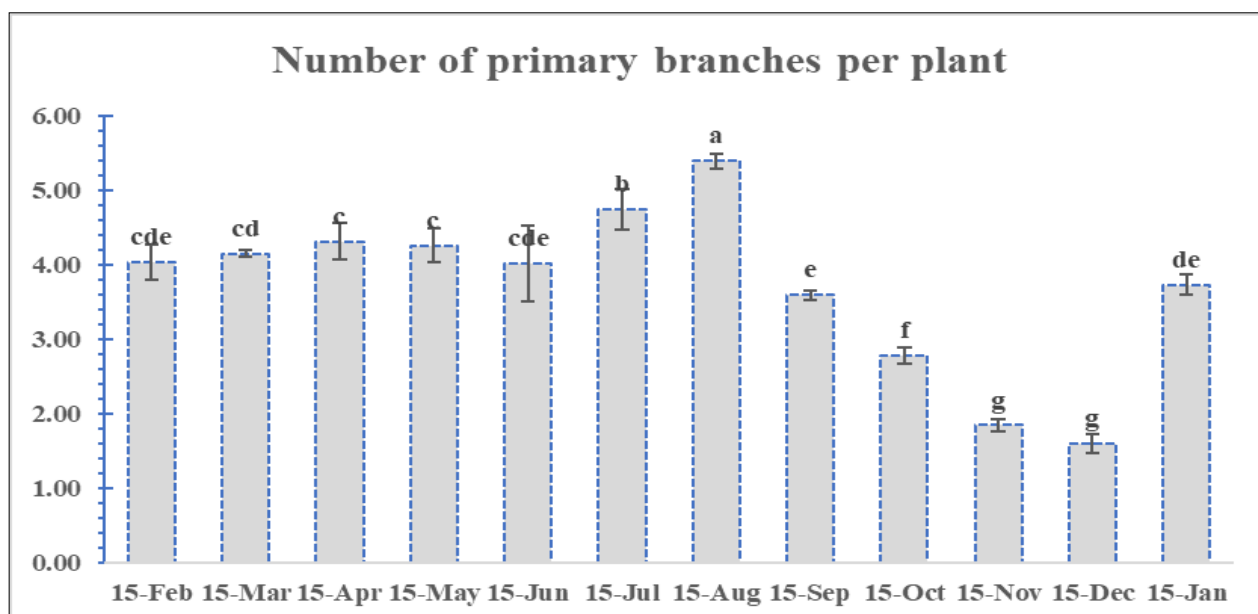


Fig. 5. Effect of year-round transplanting on number of primary branches per plant in African marigold cv. Punjab Gaiinda No. 1. Main values in each bar diagram with the same letter are not significantly different at $p < 0.05$ according to Duncan's multiple range test (DMRT).

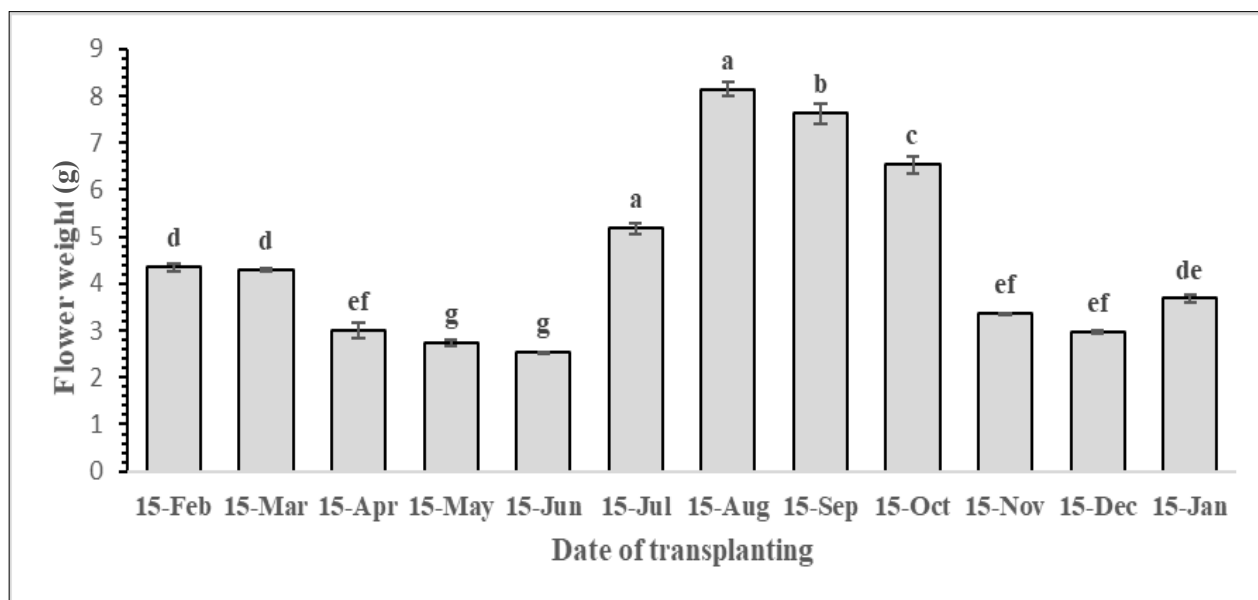


Fig. 6. Effect of year-round transplanting on flower weight (g) in African marigold cv. Punjab Gaiinda No. 1. Main values in each bar diagram with the same letter are not significantly different at $p < 0.05$ according to Duncan's multiple range test (DMRT).

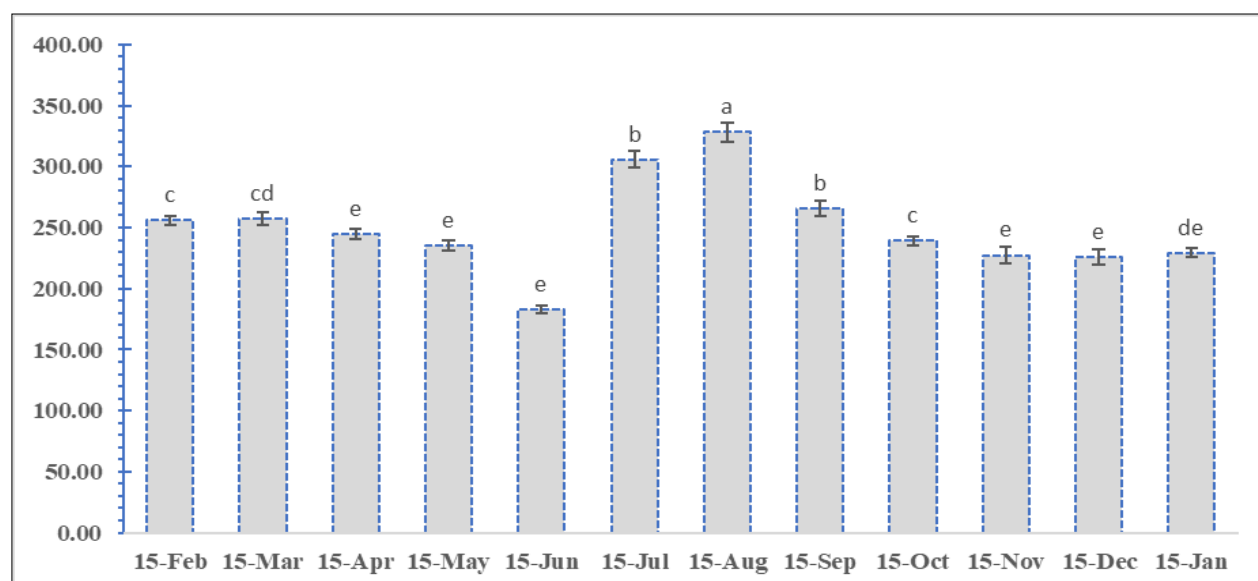


Fig. 7. Effect of year-round transplanting on flower yield g m^{-2} in African marigold cv. Punjab Gaiinda No. 1. Main values in each bar diagram with the same letter are not significantly different at $p < 0.05$ according to Duncan's multiple range test (DMRT).

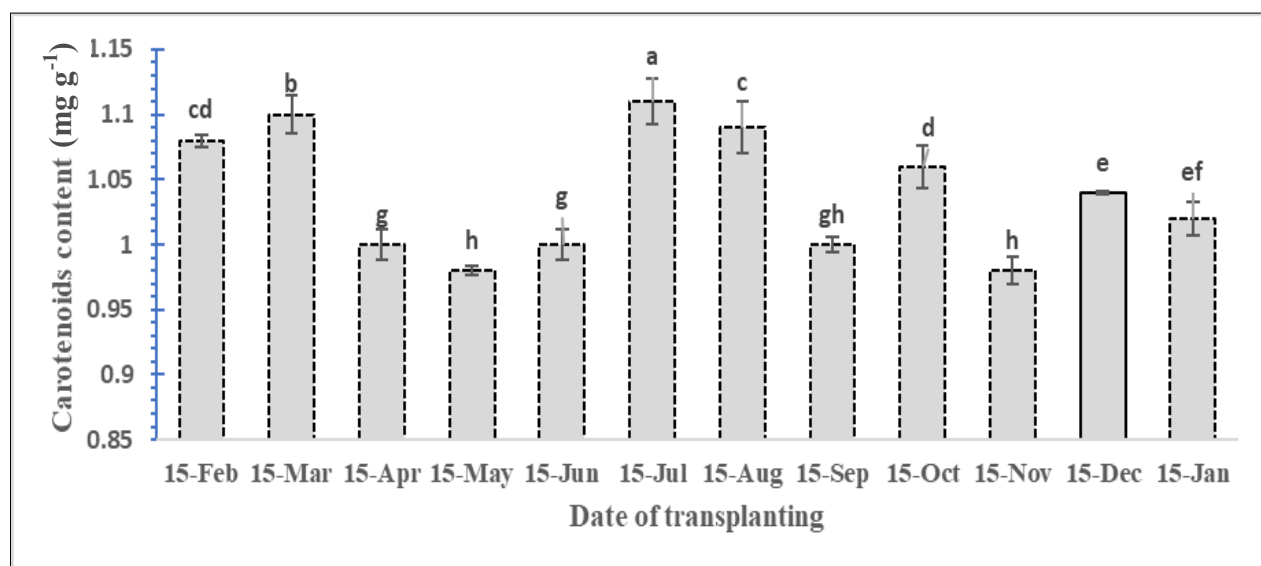


Fig. 8. Effect of year-round transplanting on carotenoids content in African marigold cv. Punjab Gaiinda No. 1. Main values in each bar diagram with the same letter are not significantly different at $p < 0.05$ according to Duncan's multiple range test (DMRT).

quantified substantially in lower quantities.

The ANOVA showed very significant effects of treatment on all the parameters quantified for growth, floral displays and physiology implying that experimental treatments have a great impact on plant performance (Supplementary Table 1).

For growth traits like vegetative stage, shoot length, spread of the plant, number of principal branches per plant, BL and BD evidenced very high F -values (from 52.80 to 4419.54) with almost zero probability levels (< 0.001). This clearly indicates that there is a wide difference in the response to treatments rather than experimental errors alone. In contrast, replication effects were non-significant for these traits also ($p > 0.05$) suggesting uniformity in experimental conditions and minimum environmental heterogeneity across blocks. This is also observed from relatively low residual mean squares which further confirm the preciseness and reliability of the experimental design system.

The reproductive parameters also showed pronounced treatment responses. Fissure weight and yield registered very high F value (977.68, 6287.21 respectively; $p < 0.001$) which points that yield attributes were highly under the influence of treated

application. Although replication effects for FW approached marginal significance ($p = 0.061$), they remained statistically non-significant so that the consistency of observations across replications was confirmed by this approach only.

Also, physiological traits were sensitive to the treatment variable. The SPAD values (SPD) for chlorophyll displayed an incredibly significant treatment effect ($F = 274.69$; $p < 0.001$) which means that treatments differ essentially in their photosynthetic potential rate (Fig. 9). The CR also showed a significant difference ($F = 11.22$; $p < 0.001$), but it was less pronounced than in other characteristics which may suggest more equal treatment influence as compared to crop growth and yield parameters. The ANOVA results show that treatments were the main source of variation over all measured traits and replication effects were still statistically non-significant. This pattern indicates the experimental design and verifies that the observed dissimilarities are treatable and not because of random environmental variations. Moreover, it was observed through PCA using standardised variables that first two principal components (PC1 and PC2) explained 76.7 % of variability, while the first three factors described 85.4 % of collective variation, which looked like

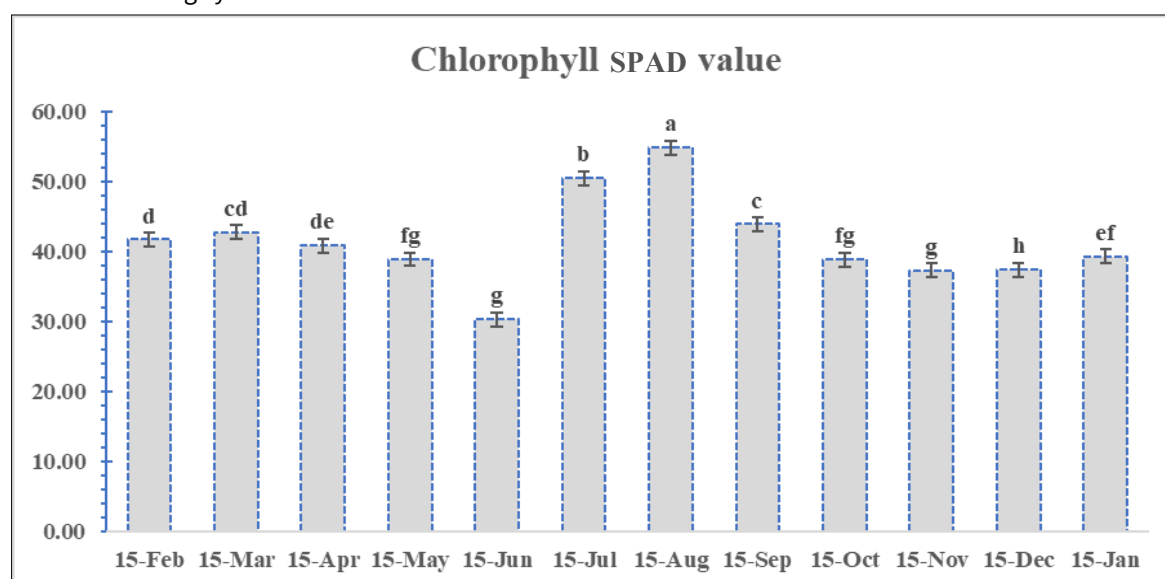


Fig. 9. Effect of year-round transplanting on chlorophyll SPAD value in African marigold cv. Punjab Gaiinda No. 1. Main values in each bar diagram with the same letter are not significantly different at $p < 0.05$ according to Duncan's multiple range test (DMRT).

most of the variables among traits can be effectively summarised by a few dominant components (Supplementary Table 2).

Correlation of the growth parameters and yield traits

A correlation analysis was conducted between vegetative growth of parameters PH, plant spread, PB per plant and yield attributes in Punjab Gairda No. 1 to calculate correlation coefficient 'r', measuring the strength and direction of linear relationship between these flower yield attributes (Fig. 10). The study found a strong and positive correlation between the flower yield attributes. A significant link ($r \leq 0.81$) was found in the PH and their plant spread ($r = 0.89$), PB ($r = 0.95$) and with fresh weight of flower ($r = 0.90$) with flower yield and SPAD index ($r = 0.89$). Positive correlation of flower yield ($r = 0.89$) and FW ($r = 0.72$) was recorded.

Principal component analysis

The biplot Fig. 11 represents first and second principal components (PC) along x- and y-axis, accounting for 76.4 % of the

total variance. Between the two components, first principal component solely explains 47 % of the variance in the data. Among the dataset of FW, CR and sunshine hours (SUN) contributed less to the principal components as compared to the other factors. The environmental parameters viz., relative humidity (RH), MXT and minimum temperature (MNT) had significantly contribution to the PC I and PC II. Among the crop parameter, PH and plant spread contributed significantly to the PC II whereas, primary branches and chlorophyll content contributed both to PC I and PC II. Furthermore, strong contribution was observed between CR and FW; rainfall and chlorophyll content; and PH and plant spread as indicated by their nearness to each other in the biplot. Except for RH, all other variables had positively contributed to the principal components whereas, RH had negatively contributed to PC I. These findings indicate that while specific crop parameters also significantly contribute to the variance explained by these components,

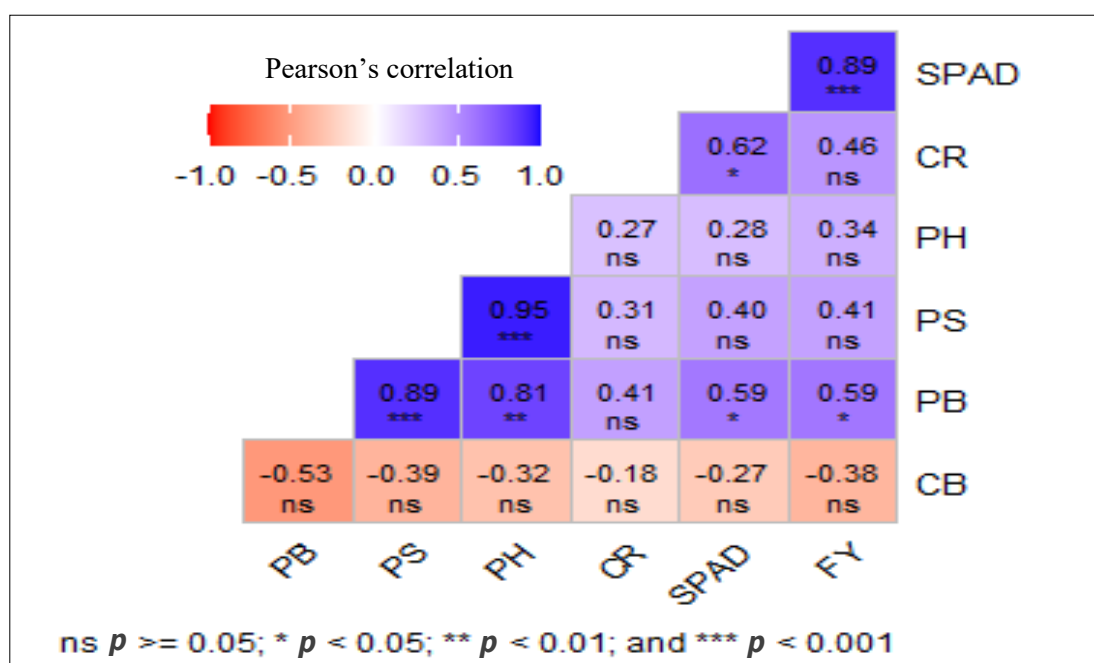


Fig. 10. Correlation of the growth parameters and yield traits.

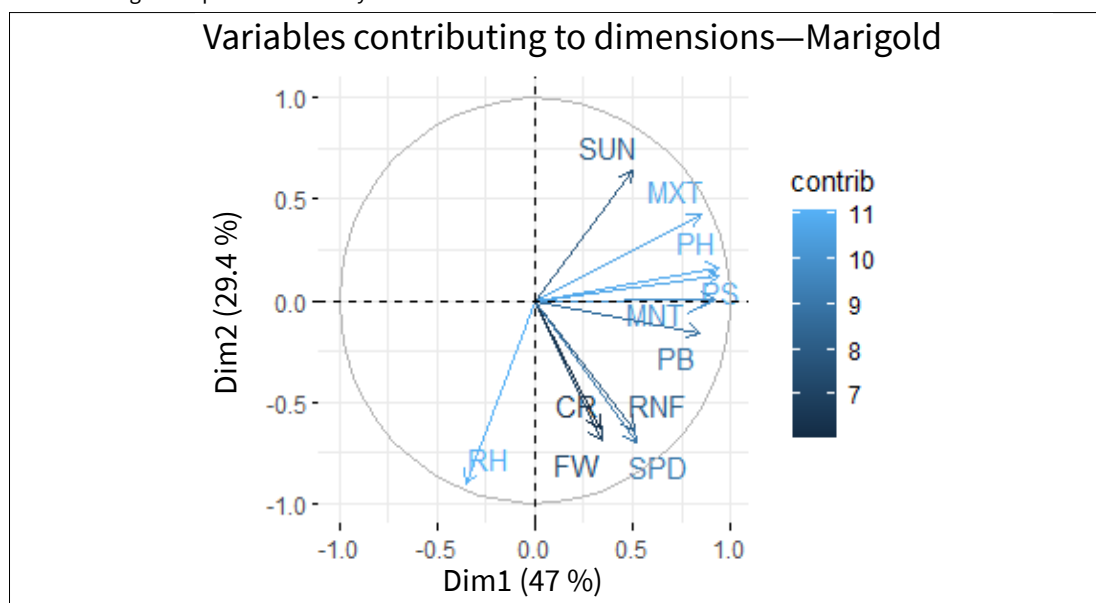


Fig. 11. Principal component analysis. SUN: sunshine hours; MXT: maximum temperature ($^{\circ}\text{C}$); PH: plant height (cm); MNT: minimum temperature ($^{\circ}\text{C}$); PB: primary branches/plant; RNF: rainfall (mm); CR: carotenoid; FW: flower weight(g); SPD: chlorophyll SPAD value; RH: relative humidity (%).

environmental factors like temperature and RH appear to be important in determining the primary components. Studying these relationships can help in optimising the conditions for better crop performance and yield.

Discussion

There was an increasing trend observed for PH up to June and July transplanting but there after decrease in PH has been recorded (Fig. 2). Variation in PH at flower bud appearance partially can be explained because the variety Punjab Gaiinda No. 1 appears to be heat tolerant and it has the genetic ability to exhibit optimum vegetative growth. So, this variety has shown the tendency to underperform in response to low temperatures as the low temperature led to many undesirable effects on plants physiological activities. As the ambient temperature (Fig. 1) has increased from February (17 °C) to June (30 °C) the PH has also progressively increased and there after decrease in temperature up to December has resulted in decrease in mean PH. The similar results also have been reported by in African marigold cv. Pusa Narangi Gaiinda where the increased PH has been quoted in response to higher ambient temperature when it was transplanted in May (3). These results are in conformity in French marigold where variation in PH was recorded in rainy and winter season planting (4, 5). Maximum plant spread and PB were recorded when transplanting was done on 15th August transplanting followed by 15th July due to its sensitivity to day length and longer daylight hours during the summer months encourage more growth. The extended daylight hours in July and August stimulate photosynthesis and overall plant development (Therefore, in July and August plants have a natural day-length of 13–13.5 hr which is enough light to promote photosynthesis, vegetative growth and flowering). Soil temperature plays a significant role in plant growth. Warmer soil temperatures in the summer months promote root development and nutrient uptake, which can lead to increased plant spread at flower bud appearance and PB per plant. Minimum plant spread and PB was recorded when transplanting was done in winter months (November and December month) due to its anticipated sensitivity to cold temperature which might have reduced plant growth significantly when the temperatures drop away (Fig. 1) from their preferred range (21 to 24 °C) for optimum growth. In November and December, many regions experience cooler weather in northern plains of India, which is not conducive to marigold growth. Similar results are reported in African marigold where minimum plant spread was recorded when transplanting was reported in October and November months (6). These results are also supported in African marigold where it recorded maximum plant spread when it was transplanted in July as compared to transplanting performed from November to January (3) and further the results are confirmed in French marigold also (7).

Number of days taken for bud appearance were statistically similar when transplanting was done between May and August or January (Table 2). However, significantly higher number of days were taken for bud appearance when transplanting was done in November and December; while statistically fewer days were taken for bud appearance when transplanting was done in the months of September and October. These results are in accordance as reported in African marigold (8).

The increase in days to colour break stage recorded from November to January might be due to winter stress conditions to be

attributed as vernalisation. Day length or photoperiod is also important in controlling flowering in marigold. Winter days are shorter and the decreased daylight hours can communicate to plants through signal transduction that it is not yet time to initiate flowering. Late winter or early spring conditions might have helped in initiation of flowering earlier through various favourable physiological processes. However earlier colour break may also be explained based on longer night and shorter day length conditions and hormonal responses in plants, which must be a signal to initiate flowering. In coreopsis, larkspur, dianthus and snapdragon earlier bud visibility was recorded with variation in temperature (9, 10).

When transplanting was done in May, June and November to January months of transplanting recorded minimum bud size and flower size of African marigold which may be attributed to extremely high and low temperatures prevalence coupled with insufficient sunlight during this growth cycle of the plant which affected the plant's ability to produce flower buds, resulting in the smaller sized flower buds. Additionally, lower temperatures may also slow, down certain metabolic processes and limit the availability of nutrients, leading to reduced size of flower buds and reduced FW and during high temperature due to heat stress. Heat stress also affects the root system of plant particularly at transplanting time and make the plant unable to uptake nutrients from soil and there by impacting plant development. From July to September recorded increased size of flower bud and FW is explained on the basis that during these growing and optimally favourable temperatures during rainy season along with longer day lengths as compared to winter months provided more sunlight for photosynthesis, the process by which plants convert the light energy in to chemical energy accumulating more carbohydrates leading to larger sized flower buds. Additionally, during these growing periods of marigold, availability of water in soil and atmosphere might have helped the plants to maintain cell turgidity, allowing to attain increased size for flower buds and FW. Similarly, very less FW of flowers has been reported in African marigold recorded when it was grown in winter months and maximum FW of flower in July months of transplanting (3, 11). From the data highest flower yield per square metre was recorded on 15th August transplanting which was reduced by about 66 % and 82 % when transplanting was done on 15th February and 15th December, as compared to transplanting done in August.

In winter months reduced yields per plant was recorded because of low temperature that significantly impact growth and development of plant and various physiological process including nutrient uptake, water absorption and metabolic activities leading to decreased flower yield per plant. Increased primary and secondary branches recorded during these months resulted in increased yield per plant as the more branches has led to a greater number of flower buds per plant and hence yield. The variations in yield during summer and winter months have also reported in African and French marigold (3, 7). Results are also in accordance as reported in *Calendula* (12) African marigold and *Gaillardia* (3, 13).

The genotypes are influenced by climatic conditions for their pigment production to adapt to the changing environmental conditions. The significant values might reflect the natural variation in total carotenoids content as the plants progress through their life cycle.

Different weather conditions influence the growth and yield of marigolds cultivated throughout the year. Plant height, PB, FW, CR

and SPD are affected by SUN and MXT. This indicates that marigold performance heavily depends on adequate sunlight and warm temperatures (Fig. 11). These conditions characterise spring, summer and early autumn, which promote vigorous vegetative growth, enhanced chlorophyll levels and better flower development. Additionally, MNT and RH are associated with winter and post-monsoon periods, showing a moderate influence on these physiological traits, suggesting a slower metabolism. As a result, growth is slower but steady during cooler nights with moderate moisture. Conversely, heavy rainfall adversely affects growth and yield, demonstrating a negative correlation. Therefore, monsoon planting often hampers plant growth, diminishes flower quality and increases vulnerability to physiological stresses and disease. Overall, PCA analysis reveals that year-round cultivation of marigolds performs best when key stages align with periods of higher sunshine hours and favourable temperature conditions.

Conclusion

In conclusion, the highest genetic potential of the crop for vegetative growth and flower production were recorded when it was transplanted on 15th August followed by 15th July. Thus, the present study concludes that African marigold should be transplanted on 15th August for obtaining optimum flower production and vegetative growth under the climatic conditions of northern plains of India.

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Authors' contributions

RK contributed to the original draft preparation, review and editing of the manuscript, methodology and data curation. RS contributed to supervision, visualisation and formal analysis. KKN contributed to review and editing of the manuscript. All authors have read and approved the final manuscript.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interest to declare.

Ethical issues: None

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