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Research Paper

Phenology, heat unit requirement and heat use efficiency of African marigold under year-round transplanting conditions of Punjab, India

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ABSTRACT

The present study was conducted during 2021-22 and 2022-23 to study crop phenology, heat unit requirement and heat use efficiency (HUE) in African marigold under year-round transplanting at Punjab Agricultural University, Ludhiana, Punjab, India. The highest heat use efficiency for seed and flower production were recorded in crop transplanted in rainy season particularly in the month of August. Higher growing degree days (GDD) and photothermal units (PTU) for attaining bud visibility and 50 % flowering stages were recorded under spring and summer transplanting (February to June) due to longer day length conditions which forced the crop to witness shorter seed filling period with lesser seed yield and HUE. Optimum seed yield period in marigold (rainy season transplanting), however, recorded lesser GDD and PTU for attainment of bud visibility and 50 % flowering as compared to summer transplanting dates and consequently had longer seed filling period resulting in higher seed yield. Notably, GDD and PTU for seed filling period recorded higher values in rainy season transplanted crop as compared to crop transplanted in other seasons of year. Correlation studies were conducted to understand the role of weather variables for high seed yield obtained under rainy season transplanting. Seed yield in African marigold recorded the highest value of correlation with HUE for seed production (r^2= 0.978) followed by GDD for seed filling period (r^2= 0.810), HUE for flower production (r^2= 0.787) and PTU for seed filling period (r^2= 0.774), respectively. Apparently, mean temperature and sunshine hours during seed filling period are the most important determinants of seed yield in African marigold.

Keywords: GDD, marigold, phenology, PTU, seed filling period, seed yield

Marigold (*Tagetes erecta* L.) is one of the most important commercial flower crops around the world. It is a member of the Asteraceae family and is native to South and Central America, particularly Mexico where it is used in traditional medicines in addition to ornamental purposes (Mahantesh *et al.,* 2018). The genus *Tagetes* contains 33 species with *Tagetes erecta* L., widely known as African marigold, and *Tagetes patula* L., commonly known as French marigold, being the most important species horticulturally and commercially. Both types of marigolds are appropriate for loose blooms in the garden and are grown commercially. It is also used as a bedding plant in the herbaceous border for adding color and filling gaps in newly planted shrubberies (Dixit *et al.,* 2013). Marigolds can be utilized as a trap crop for a variety of insect species. It is food plant for some lepidopteran caterpillars and a pollen supply for butterflies and honeybees. Marigold plants also have allelopathic effects which help to prevent nematodes. The alpha-terthienyl chemical produced in the roots has nematicide properties (Ray *et al*., 2000 and Wang *et al.,* 2007).

For optimal growth and flowering, marigold requires a mild climate. It can be sown in rainy, summer and winter seasons, allowing for year-round flower production for commercial purposes. In India, marigold was planted on 84.09 thousand hectares, yielding 916.24 metric tons of flower. Madhya Pradesh is the leading state with the highest area (42.47 thousand ha) under marigold with 289.70 tons production followed by Karnataka (16.61 thousand ha area) with 152.07 tons production (Anonymous 2021).

GDD and PTU have been reported to determine the cumulative solar radiation and temperature exposure for triggering the transition from vegetative to reproductive stages in members of family Asteraceae. Higher GDD in sunflower (belonging to same family as marigold) for bud formation and physiological maturity

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stages has been reported when transplanting was done in spring season as compared to winter season under the agro-climatic conditions of Ludhiana (Kingra *et al.,* 2007 and Dhillon *et al.,* 2017). However, information regarding heat unit requirement in African marigold is lacking under year-round transplanting conditions in Punjab.

Punjab Gainda No 1 cultivar of African marigold released by Punjab Agricultural University Ludhiana is heat tolerant and is suitable for flower production when sown in summer season. However, there are often complaints from farmers and seed producers regarding limited seed production when sown in summer. The information on optimum weather conditions for quality seed production is not available due to lack of systematic data on yield statistics when it is grown throughout the year. This study is an attempt in this direction to identify the optimum planting window for achieving higher seed production by marigold farmers/seed growers in the Punjab state and also to understand the role of weather variables in determining the seed yield of African marigold.

MATERIAL AND METHODS

Field experiments were conducted during 2021-22 and 2022-23 at Research Farm of Department of Floriculture and Landscaping, Punjab Agricultural University, Ludhiana, (30° 54' N, 75° 48' E, altitude 247 m above mean sea level). The meteorological data were collected during crop growth period from the Department of Climate Change and Agricultural Meteorology, PAU, Ludhiana.

The seeds were sown on raised nursery beds starting from January throughout the year. The raised beds were prepared by mixing 5 kg well decomposed FYM per square meter area. The seeds were sown in line, each line was sown 2-3 cm apart and covered with finely sieved leaf mold. The seedlings were transplanted in the main field every month when they had achieved the transplantable height (7-10 cm). The beds for transplanting of seedlings were prepared by mixing 10-15 kg of well decomposed FYM per bed and basal dose of fertilizers as per standard recommendations of PAU (Anonymous 2022). The seedlings were planted with row-to-row distance of 40 cm and plant to plant spacing of 40 cm in beds. The experiment was conducted in randomized complete block design (RCBD) with twelve planting dates.

Data were recorded on various phenological stages *viz.,* days to bud visibility, days to 50 % flowering and days to seed harvesting. Seed filling period was calculated by subtracting the days to 50 % flowering from days to seed harvesting. Fresh flower yield was recorded at full blooming stage. Fully matured heads of flowers were harvested and dried at ambient temperature before recording seed yield. Harvest index (HI) was calculated as seed yield (kg/ha)/ Biological yield (kg/ha). Growing degree days (GDD) was calculated as per De Beurs and Henebry (2008) and base temperature was taken as 4.5 °C using the following formula:

$$\text{GDD}(°\text{C Day}) = \frac{\text{Tmax} + \text{Tmin}}{2} - \text{Tbase}$$

Where, Tmax = Daily maximum temperature (ºC)

Tmin = Daily minimum temperature (ºC)

Tb = Base temperature (ºC)

Photothermal units were calculated as described by Kaur *et al.,* (2019) using the following formula:

PTU (˚C Day hr) = (GDD) X (Day length)

Heat use efficiency (HUE) was calculated as described by Singh and Khushu (2012) using the following formula:

$$\text{HUE (g m}^{-2}\,°\text{C day}^{-1}) = \frac{\text{Dry matter yield (g m}^{-2})}{\sum\text{GDD (°C Day)}}$$

The data were subjected to analysis of variance (ANOVA) using R software version (2.2.0) programme. Correlation analysis was conducted using SAS 9.3 software.

RESULTS AND DISCUSSION

Phenology of African marigold

Number of days taken for bud appearance were statistically similar when transplanting was done between May and August or January. However, statistically 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. Number of days taken to 50 % flowering were also significantly influenced by planting date of African marigold. Time taken to 50 % flowering was the highest in crop transplanted in winter season followed by crop transplanted in the months between May and July. Crop took the highest number of days to harvest when transplanting was done in the month of December which may be attributed to low temperature experienced by the crop during early stages of crop growth. Crop transplanted in the month of August took about 147 days which was statistically at par to crop transplanted in November. There was significant reduction in the number of days taken for attaining harvest maturity when crop was transplanted in other months of the year (Table 1).

Seed filling period

Seed filling period in marigold pertains to number of days taken for seed harvesting after attaining 50 % flowering (Table 1). Number of days taken for seed filling were the highest in August transplanted crop followed by crop transplanted in February. Likewise, the highest seed yield was recorded in August transplanted crop but was followed by July transplanted crop (Table 2). This difference in the trend of seed yield and number of days taken for seed filling could be attributed to the fact that GDD and PTU for seed filling period were the highest in August transplanted crop followed by July transplanted crop (Table 3). Pratibha *et al.,* (2018) recorded lesser number of days to bud appearance in French marigold when transplanting was done in September and October months as compared to transplanting done in the months of April, May, June, July and August under the climatic conditions of Nauni, Solan. Dhillon *et al.,* (2017) recorded lesser number of days to 50 % flowering and seed filling stage in Sunflower (also belonging to family Asteraceae) when transplanting was done in spring season (February and March) months than transplanting done in the winter month of January under climatic conditions of Ludhiana.

Table 1: Effect of year-round transplanting on days taken for attaining various phenological stages and seed filling period in African marigold (pooled data of 2021-22 and 2022-23)

Season/Date of transplanting	Days to bud appearance	Days to 50 % flowering	Days to seed harvesting	Seed filling period (days)
Spring				
15-Febraury	57.01 cde	77.39 de	129.19 de	51.8 ab
15-March	59.18 cd	79.00 de	121.88 ef	42.88bc
Summer				
15-April	60.79 c	79.90 cde	121.38 ef	41.48bc
15 May	63.23 b	99.17 bcd	118.56 ef	19.39 d
15-June	73.34 b	99.66 bcd	122.82 ef	23.16 d
Rainy				
15-July	65.90 b	92.28 bcd	134.35 cd	42.07bc
15-August	67.50 b	88.78 cd	146.64 b	57.86 a
Autumn				
15-September	53.11 de	74.67 e	117.39 f	42.72bc
15-October	52.22 e	72.61 e	112.57 f	39.96bc
Winter				
15-November	85.00 a	110.56 a	149.61 b	39.05 c
15-December	86.89 a	111.89 a	161.88 a	49.99abc
15-January	72.88 b	92.11 b	142.14 bc	50.03abc

Mean values in each column with the same letter are not significantly different at $p < 0.05$ according to Duncan's Multiple Range test (DMRT).

Table 2: Effect of year-round transplanting on seed yield, harvest index and heat use efficiency (HUE) of African marigold (pooled data of 2021-22 and 2022-23).

Season/ Date of transplanting	Seed yield (g plant^{-1})	Seed yield (kg ha^{-1})	Harvest index	HUE for seed production (g m^{-2} °C Day^{-1})	HUE for flower production (g m^{-2} °C Day^{-1})
Spring					
15th -February	6.15 d	38.44 d	0.012 de	0.0127 cd	0.5541 cd
15th -March	5.74 d	35.88 d	0.008 de	0.0082 d	0.3955 de
Summer					
15th -April	5.71 d	35.69 d	0.011 de	0.0109 cd	0.1878ef
15th- May	3.83 de	23.94 de	0.012 de	0.0107 cd	0.1438ef
15th -June	4.58 de	28.63 de	0.016 cd	0.0150 cd	0.1089 f
Rainy					
15th- July	24.53 b	153.31 b	0.039 b	0.0539 b	0.6929 c
15th- August	51.09 a	319.31 a	0.060 a	0.1065 a	1.2057 a
Autumn					
15th-September	14.83 c	92.69 c	0.021 c	0.0497 b	0.9654 ab
15th -October	5.01 de	31.31 de	0.007 de	0.0225 c	0.7915bc
Winter					
15th -November	3.42 de	21.38 de	0.010 de	0.0125 cd	0.2126ef
15th-December	1.36 e	8.50 e	0.004 e	0.0040 d	0.1301ef
15th-January	3.96 de	24.75de	0.008 de	0.0092 d	0.3197 def

Mean values in each column with the same letter are not significantly different at $p < 0.05$ according to Duncan's Multiple Range test (DMRT).

Seed yield, harvest index and heat use efficiency

The highest seed yield per plant was recorded in August transplanting which was reduced by about 52 and 71 % when transplanting was done in July and September, respectively. In other planting dates, reduction in seed yield per plant varied from 88.0 % (February) to 97.3 % (December) as compared to transplanting done in August (Table 2). The highest heat use efficiency for seed production was observed in August transplanting followed by July transplanting which was statistically at par to September transplanting. Likewise, the highest HUE for flower production was reported in August transplanting but was followed by September, October and July transplanting, respectively. Harvest index of African marigold cv. was also significantly affected by monthly interval planting. The highest harvest index was observed in August transplanting followed by July transplanting. There was progressive decrease in harvest index when crop was transplanted from September to December (Table 2). Pramila *et al.,* (2011) recorded

Table 3: Effect of year-round transplanting on growing degree days (GDD) and photothermal units (PTU) of African marigold (pooled data of 2021-22 and 2022-23).

Date of transplanting	Growing degree days (GDD) (°C Day)				Photothermal units (PTU) (°C Day hr)			
	Days to bud visibility	Days to 50 % flowering	Seed filling period (Days)	Days to seed Harvesting	Days to bud visibility	Days to 50 % flowering	Seed filling period (Days)	Days to seed Harvesting
Spring								
15th -February	997de	1498e	883bcde	2892abc	11825ef	18323 d	10413bcd	37457abc
15th -March	1346c	1880bcd	918bcd	3053abc	17107 d	24337c	11429bc	40813ab
Summer								
15th -April	1584b	2108bc	1039bc	3179a	21355 c	28739 b	13761 ab	43255ab
15th- May	1702b	2625 a	497ef	3132a	23657 b	35962 a	6765cde	42338a
15th -June	1909a	2570a	603 def	3090ab	25983a	34134 a	8460cde	40133 ab
Rainy								
15th- July	1676b	2289b	1069ab	2991abc	21757bc	28906b	14199 ab	36436bc
15th- August	1618b	1990cd	1423a	2599cd	19644 c	23652c	17447a	29869d
Autumn								
15th-September	1118d	1427e	941bcd	1811e	12790 e	15989de	10891bcd	19868e
15th -October	825 f	1012f	669cdef	1310f	8767gh	10680f	7200cde	13727 f
Winter								
15th -November	787f	1103f	432f	1851e	8046 h	11565f	4403 e	20580e
15th-December	839ef	1315e	368f	2422d	8989gh	14730e	3759 e	29185d
15th-January	930ef	1352e	523ef	2629bcd	10491fg	15737de	5676de	32824cd

Mean values in each column with the same letter are not significantly different at $p < 0.05$ according to Duncan's Multiple Range test (DMRT).

higher seed yield per plant in African and French marigold during *Kharif* season planting but recorded better seed quality parameters *viz*. germination and vigour indices in *rabi* season planting.

Growing degree days (GDD) and photothermal units (PTU)

The crop transplanted in summer season (particularly May and June) accumulated higher GDD and PTU to attain days to bud visibility followed by progressive decrease in GDD and PTU thereafter under rainy and autumn season transplanting. This was followed by progressive and continuous increase in GDD and PTU under winter and spring season transplanting, respectively in African marigold. The trend observed for GDD and PTU was similar for other phenological stages namely days to 50 % flowering and seed harvesting. The highest GDD to attain seed harvesting was recorded in June transplanting and it was 15.9 % higher as compared to August transplanting.

In contrast to the trend of GDD and PTU observed for attaining phenological stages *viz*., days to bud visibility, days to 50 % flowering and days to seed harvesting, the trend observed for seed filling period presented different scenario. We recorded the highest GDD and PTU for seed filling period in rainy season transplanted crop. Another important finding of this study is that although seed filling period was statistically similar when crop was transplanted in March/April/July/ September/October months but seed yield was the highest in July transplanted crop which recorded the highest GDD and PTU amongst the above-mentioned months. Among the above-mentioned months, the lowest seed yield was recorded in October transplanted crop which witnessed least GDD and PTU. This clearly indicates that temperature and day length are the most important weather factors which govern seed yield in African marigold (Tables 1, 2 and 3). Rao *et al.,* (2002) reported that African and French marigold accumulated higher GDD for vegetative and flowering stages in summer month (June) planting as compared to rainy, autumn and winter months transplanting at IARI, New Delhi. This explains the direct effect of temperature on crop growth as a specific quantity of GDD is required to progress to the next crop stage. Kingra *et al.,* (2007) recorded higher growing degree days in sunflower (belonging to same family as marigold) for bud formation and physiological maturity stages when transplanting was done in February month (spring) as compared to December and January months (winter) under the agro-climatic conditions of Ludhiana. In present study, the crop transplanted in summer season recorded higher GDD and PTU to attain phonological stages *viz.,* bud visibility, 50 % flowering and seed harvesting due to longer day length and thus witnessed shorter seed filling period. However, higher GDD and PTU were recorded for seed filling period under rainy season transplanting in marigold and consequently higher flower and seed yield were obtained under rainy season transplanting as compared to other seasons of the year.

Correlation studies

In present study, seed yield had non-significant correlation with days to attain various phenological stages *viz*., bud appearance, 50 % flowering and seed harvesting; however, days to seed filling were significantly and positively correlated with seed yield of African marigold. Correlation studies indicated that seed yield in African marigold recorded the highest value of correlation with HUE for seed production (r^2= 0.978) followed by GDD for seed filling period (r^2= 0.810), HUE for flower production (r^2= 0.787) and PTU for seed filling period (r^2= 0.774), respectively. Apparently, mean temperature and sunshine hours during seed filling period are the most important determinants of seed yield in African marigold (Table 4).

Table 4: Correlation of seed yield of marigold with phenological stages and agrometeorological indices

Parameters	Correlation coefficient
Days to bud appearance	-0.227^{NS}
Days to 50 % flowering	-0.145^{NS}
Days to seed harvesting	0.189^{NS}
Days for seed filling	0.446**
GDD for bud appearance	0.375*
GDD to 50 % flowering	0.221^{NS}
GDD to seed filling	0.809**
GDD to seed harvesting	0.034^{NS}
PTU for bud appearance	0.287^{NS}
PTU for 50 % flowering	0.140^{NS}
PTU for seed filling	0.773**
PTU for seed harvesting	-0.074^{NS}
HUE for seed production	0.977**
HUE for flower production	0.786**

*=significant at 5 %, ** = significant at ١ ٪ and ^{NS} = non-significant

CONCLUSION

In present study, African marigold witnessed longer seed filling period and consequently higher GDD and PTU for seed filling period resulting in higher flower and seed yield under rainy season transplanting as compared to other seasons of the year.

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