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Seed yield and quality of African marigold (*Tagetes erecta*) under year-round transplanting conditions in northern plains of India

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ABSTRACT

African marigold (*Tagetes erecta* L.) cv. Punjab Gainda No. 1 is the most popular cultivar with bright orange marketable double flower. Being the farmers' cultivar of choice for year-round cultivation, the problem of seed setting in summers and lack of availability of quality seed for plantations directly leads to huge economic losses. This study was carried out during 2021–2023 at Punjab Agricultural University, Ludhiana, Punjab to check the seed yield and quality of Punjab Gainda No. 1 under year-round transplanting conditions in the northern plains of India. The experiment was laid out in a randomised complete block design (RCBD) with 12 transplant dates on the 15th of each month year-round for assessing the optimum planting window for maximising seed yield and quality. Mid-July to Mid-September transplanted crops exhibited better seed yield and quality due to favourable environmental conditions supporting vegetative growth and seed filling. Mid-August transplanting yielded the highest seed yield and quality including germination rate and seedling vigour indices. Seeds from this period exhibited higher accumulation of seed reserves and higher activities of enzymes – dehydrogenase and α-amylase which play crucial roles in seed viability and germination, respectively. Conversely, winter and summer transplanting yielded poorer seed quality due to adverse climatic conditions affecting seed development. Overall, mid-August transplanting is the best time period to ensure maximum seed yield and quality in African marigold for achieving successful seed production in the northern plains of India.

Keywords: α-amylase, Dehydrogenase, Marigold, Seed reserves, Seed quality, Seed yield

Marigold (*Tagetes erecta* L.) is a globally sought-after commercial flower crop for its immense environmental and economic benefits. It is widely used in religious and social gatherings and planted as a trap crop to attract various insect species. Marigold, a native of South and Central America, has been used for ornamental purposes, traditional medicines and livestock feed since ancient times (Mahantesh *et al.* 2018). The genus houses 33 species chiefly, including African (*Tagetes erecta* L.) and French marigold (*T. patula* L.). Commercial growers cultivate both types for their short duration and free flowering nature in gardens as well as for making herbaceous flower garden borders (Dixit *et al.* 2013). In India, marigold cultivation covers a substantial area, with a dedicated 84.1 thousand hectares land yielding 916.2 thousand million metric tonnes of loose flowers in a year with Madhya Pradesh and Karnataka being the leading states in marigold production (Anonymous 2021).

Quality of seed, being the only propagation material for marigold plantations, has major influence on the crop performance and flower yield. Poor emergence rates and crop stand, weak seedlings, genetic impurities and seed-borne diseases are a few chief challenges faced by the growers which can diminish the uniformity and performance of the crop, resulting in yield losses. Thus, Indian Minimum Seed Certification Standards adheres to stringent standards to address these challenges including purity (97%), germination rate (70%) and seed moisture content (9% in moisture pervious packaging and 7% in vapour proof containers), ensuring the quality of certified marigold seeds for successful cultivation (Anonymous 2013).

Punjab Gainda No. 1 is the most popular African marigold cultivar of choice, featuring bright orange flowers, shorter crop production time and higher yield. However, growing it as a summer crop has encountered seed setting issues forcing farmers and seed producers to go for spurious seeds from unconfirmed sources for year-round cultivation (Sehgal *et al.* 2018). Therefore, field and laboratory studies were conducted to determine the ideal planting window for obtaining higher seed yield and optimum seed quality in African marigold by undertaking studies on seed yield and quality from year-round crop transplantation under India's northern plains climatic conditions.

MATERIALS AND METHODS

The on-site investigations were carried out during

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the years 2021–22 and 2022–23 at Punjab Agricultural University, Ludhiana (30.9°N, 75.85°E; at an elevation of 247 m amsl), Punjab. The agrometeorological data were obtained from the Department of Climate Change and Agricultural Meteorology, Punjab Agricultural University, Ludhiana, Punjab during the crop growth period (Fig. 1).

The seeds of African marigold cv. Punjab Gainda No. 1 were procured from Department of Floriculture and Landscaping, PAU, Ludhiana. Nursery was made on raised beds throughout the year starting from January. The nursery beds were prepared by mixing well decomposed farm yard manure @5 kg/m^2. The seeds were sown in lines erected 2–3 cm apart and covered with leaf mould as mulch and soil conditioner. The beds were watered with rose cane at least twice a day during morning and evening hours. The seedlings of equivalent size and vigour were transplanted in the main field on 15th of each month following their achieving transplantable height of 7–10 cm. The transplanting beds were prepared by mixing the standard PAU recommended basal dose of fertilisers, viz. urea (320 kg/acre), single superphosphate (250 kg/acre), muriate of potash (66 kg/acre) and well decomposed farm yard manure @10–15 kg/m^2 (Anonymous 2022). The plants were pinched 30 days after transplanting and regular cultural operations were followed during growth period. The fully mature flowers were harvested from the field and were kept at ambient temperature for few days before separating the seeds from the flowers. The trial was conducted on 12 planting dates year-round in a randomised complete block design (RCBD).

The harvested seeds were analysed for various seed quality parameters, viz. 1000 seed weight (g), germination percentage, seedling length (cm), seedling dry weight (g), seedling vigour index-I and II, dehydrogenase activity, α-amylase activity, total free amino acid content, total soluble sugar content, starch content and total soluble protein content in the Seed Physiology Laboratory, Office of Director (Seeds), Punjab Agricultural University, Ludhiana, Punjab. For germination, 100 seeds were put onto moistened germination paper with three replications per treatment. The moistened germination papers were then incubated at 25 ± 2°C. After eight days, seeds exhibiting both radicle and plumule emergence were considered as germinated. From the eight days old seedlings, ten representative seedlings were selected for the measurement of root length and shoot length using meter scale. Following which, seedling dry weight was recorded after putting them into paper packets followed by their placement into the preheated oven at 70 ± 2°C till the attainment of constant weight. The dry weights obtained were recorded on an electronic balance after cooling in desiccators and expressed in grams. Seedling vigour index-I was calculated following Abdul-Baki and Anderson (1973):

$$\text{Seedling vigour index-I} = \text{Germination \%} \times \text{Mean seedling length (cm)}$$

Seedling vigour index-II was calculated as per Kharb *et al.* (1994):

$$\text{Seedling vigour index-II} = \text{Germination \%} \times \text{Seedling dry weight (g)}$$

Seedling dry weight was recorded of 10 seedlings. Seeds were analysed for storage reserves, viz. total soluble protein content (Lowry *et al.* 1951), starch (Clegg 1956), total soluble sugar content (Dubois *et al.* 1956) and total free amino acid content (Lee and Takahashi 1966) using the standard methods for extraction and estimation. Dehydrogenase activity was read and expressed as absorbance at 485 nm as per procedure laid out by Kittock and Law (1968). The activity of α-amylase was determined from seeds imbibed in water for 24 h as per procedure laid out by Sadasivam and Manickam (1996).

The data obtained for both the years were pooled for the comparison of treatments. Critical difference and standard error values were calculated via statistical tests- ANOVA and DMRT as post-hoc test. Correlation analysis was conducted using R statistical software version 2.2.0.

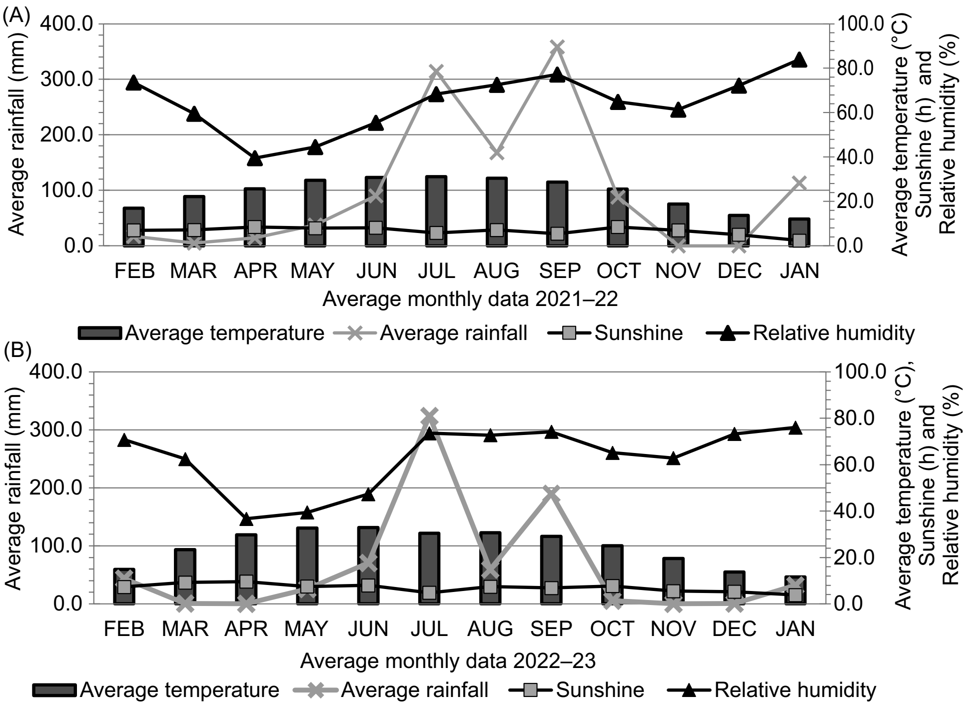

Fig. 1 Year-round mean monthly meteorological data during (A) 2021–22 and (B) 2022–23.

RESULTS AND DISCUSSION

Seed yield and associated attributes: The highest number of seeds/ flower (338) was recorded in

August transplanting followed by February (275) and July (271) transplanting (Table 1). The least number of seeds/flower (151) was recorded in 15th June transplanting which was statistically at par to May transplanting. Transplanting after 15th October resulted in progressive decrease in number of seeds/flower till 15th December transplanting. Likewise, August transplanted crop recorded the highest seed yield/plant which reported a decline of 42% and 68% amongst July and September transplanted crop, respectively (Table 1). A sharp decline varying from 87% (February) to 97% (December) was recorded in seed yield/plant in other planting dates as compared to August transplanted crop. The variation in seed yield across transplanting dates can be primarily attributed to differences in duration of seed filling. Crops transplanted during mid-July to mid-September experience favourable temperature regimes and optimal growing degree day (GDD) accumulation, which ensures efficient assimilate partitioning and extended seed filling duration, ultimately resulting in higher seed yield. In contrast, crops exposed to extreme summer or winter conditions suffer from either heat or cold stress, leading to reduced metabolic efficiency and shortened grain filling period (Kumar *et al.* 2023).

Similar trends of decline in yield attributes under sub-optimal transplanting periods have also been reported in other ornamental crops, where extreme environmental conditions during reproductive stages adversely affect seed set and development (Sharma *et al.* 2015a). The pronounced variation in seed yield across transplanting windows observed in the present study is in agreement with findings of recent studies in marigold, which demonstrated that transplanting time significantly affects growth, reproductive efficiency and yield due to differential exposure to temperature and photoperiod regimes (Patel *et al.* 2025, Waingankar *et al.* 2025).

The highest 1000 seed weight (2.64 g) was recorded in 15th August transplanting followed by 15th September and 15th July transplants, respectively. The least seed weight was recorded in 15th January transplanting which was statistically at par to 15th December and 15th February transplanting (Table 1). The higher seed weight obtained when transplanting was done from 15th July to 15th September which can be attributed to enhanced accumulation of photo-assimilates under favourable environmental conditions, particularly optimum temperature and humidity during seed filling. When crop was transplanted during winter (November–January), spring (February–March) and dry summer months (April–June), the seeds obtained exhibited a lower 1000 seed weight (Table 1) due to poor crop growth and unfavourable temperature and humidity which coincided with seed filling and maturation phases (Fig. 1), as also corroborated by reports of Sehgal *et al.* (2018) on detrimental effect of high temperature during significant seed developmental phases. Sharma *et al.* (2015b) recorded the highest 1000 seed weight in chrysanthemum during September and October months planting under relatively mild temperature conditions, which resulted in better seed filling; while recorded lower seed weight in the plantations done in the extreme winter months of November and December under the mid-hills of Himachal Pradesh.

Table 1 Effect of year-round transplanting on yield attributes and seed yield of African marigold cv. Punjab Gainda No. 1 (pooled data of 2021–22 and 2022–23)

Season/Month of transplanting	Number of seeds/flower	Seed yield/plant (g)	1000 seed weight (g)
Spring			
15th February	$274.98^{b} \pm 1.98$	$6.11^{d} \pm 0.08$	$0.70^{i} \pm 0.010$
15th March	$260.18^{c} \pm 2.68$	$4.24^{d} \pm 0.56$	$0.80^{h} \pm 0.015$
Summer			
15th April	$249.51^{d} \pm 2.48$	$5.76^{d} \pm 0.12$	$1.01^{g} \pm 0.005$
15th May	$153.50^{h} \pm 1.70$	$5.64^{de} \pm 0.84$	$1.30^{e} \pm 0.010$
15th June	$150.67^{h} \pm 2.15$	$7.93^{de} \pm 1.63$	$1.74^{d} \pm 0.025$
Rainy			
15th July	$270.72^{b} \pm 5.23$	$26.92^{b} \pm 1.97$	$1.92^{c} \pm 0.030$
15th August	$338.39^{a} \pm 4.98$	$46.16^{a} \pm 0.91$	$2.64^{a} \pm 0.065$
Autumn			
15th September	$235.34^{e} \pm 2.01$	$14.98^{c} \pm 0.50$	$2.07^{b} \pm 0.010$
15th October	$191.39^{f} \pm 2.19$	$4.93^{de} \pm 0.24$	$1.20^{f} \pm 0.010$
Winter			
15th November	$190.07^{f} \pm 0.19$	$3.87^{de} \pm 0.24$	$1.19^{f} \pm 0.010$
15th December	$177.67^{g} \pm 0.22$	$1.61^{e} \pm 0.10$	$0.70^{i} \pm 0.020$
15th January	$249.43^{d} \pm 0.29$	$3.99^{de} \pm 0.07$	$0.50^{i} \pm 0.010$

Mean values in each column with the same letter are not significantly different at $p \leq 0.05$ according to Duncan's multiple range test. Values are given as mean ± SE computed from triplicates.

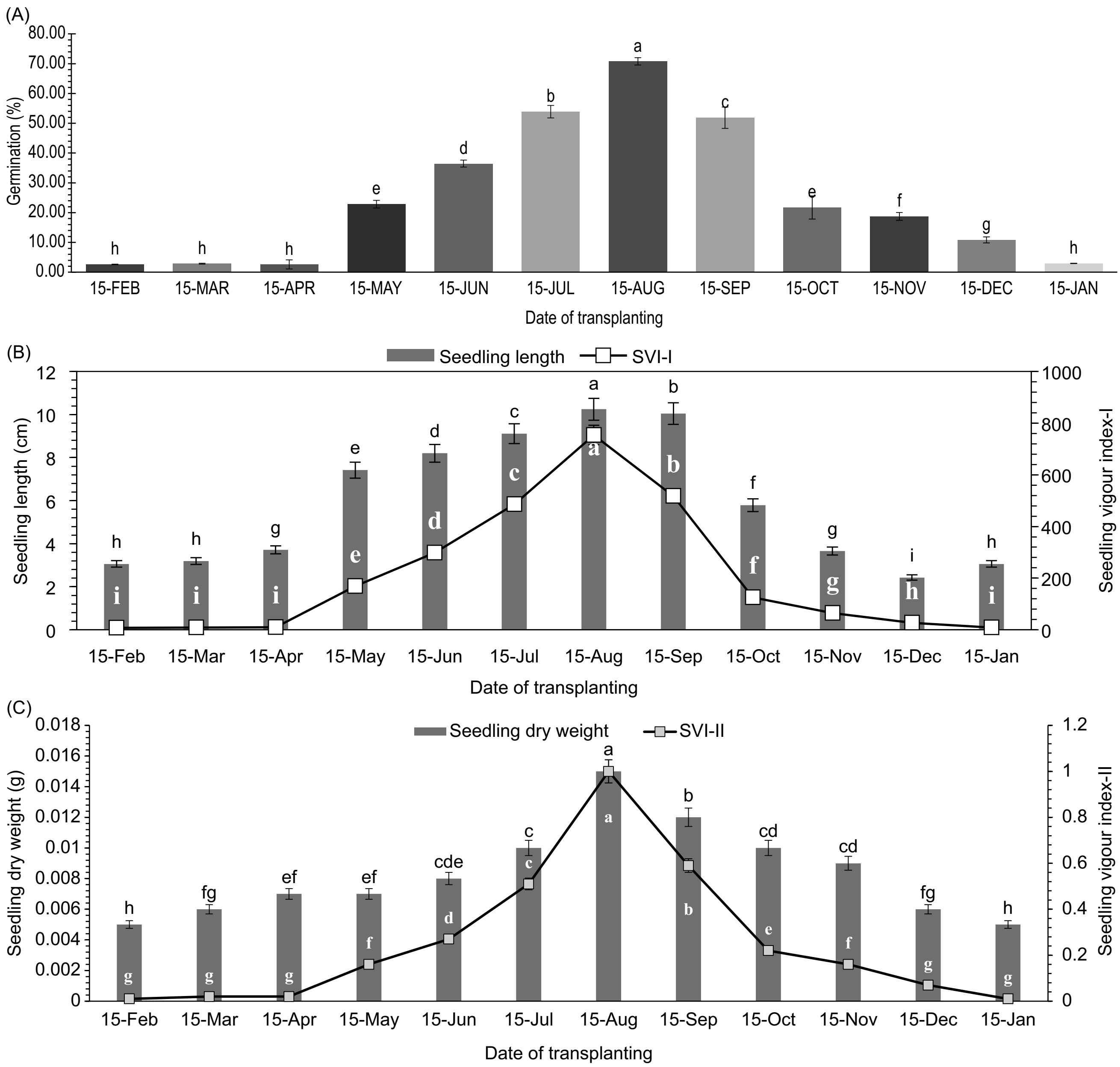

Fig. 2 Effect of year-round transplantation on (A) Germination percentage, (B) Seedling length (cm) and seedling vigour index-I, and (C) Seedling dry weight and seedling vigour index-II in African marigold cv. Punjab Gainda No. 1 (pooled data of 2021–22 and 2022–23).

Mean values in each column with the same letter are not significantly different at $p \leq 0.05$ according to Duncan's multiple range test. Bars on the graph indicate standard error computed from replications. SVI, Seedling vigour index.

Seed germination and vigour indices: The highest germination percentage was recorded in 15th August transplanting (70.8%) followed by 15th July and September transplanting, respectively. The least germination percentage (2.62%) was recorded in seeds obtained from 15th February transplanting which was statistically at par to seeds obtained from 15th January, March and April transplanting (Fig. 2A). The highest seedling length was likewise recorded in 15th August transplanting (10.24 cm) which was followed by 15th September and 15th July transplanting. Seedling vigour index-I (SVI-I) is a function of seedling vigour based on germination (%) and total seedling length. Trend observed for SVI-I was similar to seedling length. The highest SVI-I was documented in 15th August transplanting (70.8) followed by 15th September and 15th July transplanting, respectively (Fig. 2B). Similarly, the highest SVI-II was noticed in 15th August transplanting (1.06) followed by 15th September and 15th July transplanting, respectively (Fig. 2C). Apparently, marigold crop should be transplanted in the second fortnight of August for obtaining higher seed yield, germination percentage and early seedling vigour.

Similar improvements in seed germination and vigour under optimum planting windows have been reported in marigold and other ornamental crops, wherein favourable environmental conditions during seed development enhance reserve accumulation and seed physiological quality (Waingankar *et al.* 2025). This further substantiates that optimisation of transplanting time is crucial for achieving superior seed quality.

The seeds obtained from crop transplanted during July to September had higher seed weight due to greater allocation and accumulation of storage reserves, which supported better early seedling vigour and growth. In contrast, crops transplanted during winter and summer exhibited poor growth, resulting in smaller seeds with reduced germination and weaker seedlings. Similar trends have been reported in marigold, where optimum planting windows favour better seed development and vigour due to favourable environmental conditions (Waingankar *et al.* 2025). Mathad *et al.* (2008) also observed that seedling vigour index in aster was significantly improved under October planting, primarily due to higher seed weight and greater accumulation of food reserves, whereas delayed planting reduced seedling vigour. Likewise, Pramila *et al.* (2011) reported higher seed germination and vigour indices in both African and French marigolds under favourable seasonal conditions.

Biochemical seed viability markers: Dehydrogenase activity and α-amylase activity can be collectively referred to as biochemical seed viability markers ensuring the optimum viability and efficient germination of the seed. The highest dehydrogenase activity was recorded in 15th August planting that was statistically similar to 15th September and 15th July transplanting (Fig. 3A). Dehydrogenase activity was the lowest in February transplanting and was statistically similar to March and January transplanting. Szczerba *et al.* (2021) reported highest dehydrogenase activity in soybean seeds when average temperature was 25°C during grain filling and lowest was recorded when temperature was low i.e. 15°C during grain filling. Plazek *et al.* (2018) also recorded the lowest dehydrogenase activity in lupin seeds when temperature was low (7°C) at the time of grain filling. Dehydrogenase activity is an indicator of seed viability and respiration during germination of seeds. The seeds obtained from July to September transplanted crop exhibited higher dehydrogenase activity which may be attributed to enhanced reserve accumulation and improved metabolic activity during seed development under favourable environmental conditions.

The highest α-amylase activity was recorded when transplanting was done on 15th August followed by 15th July transplanting that was statistically similar to 15th September, 15th June and 15th May transplanting (Fig. 3B). Other transplanting dates recorded lower activity of α-amylase than seeds obtained from May to September transplanting. Wang *et al.* (2018) reported lower activity of this enzyme in rice when temperature was low during the seed filling period. Likewise, Szczerba *et al.* (2021) reported lower activity of alpha amylase in soybean when average temperature was low at the time of grain filling. The enzyme α-amylase has a significant impact on the breakdown of the starch granules present in the endosperm of marigold seeds to soluble sugars that can be readily transported to the growing embryo for supporting early seedling growth. These soluble sugars released by α-amylase provide the necessary inputs for

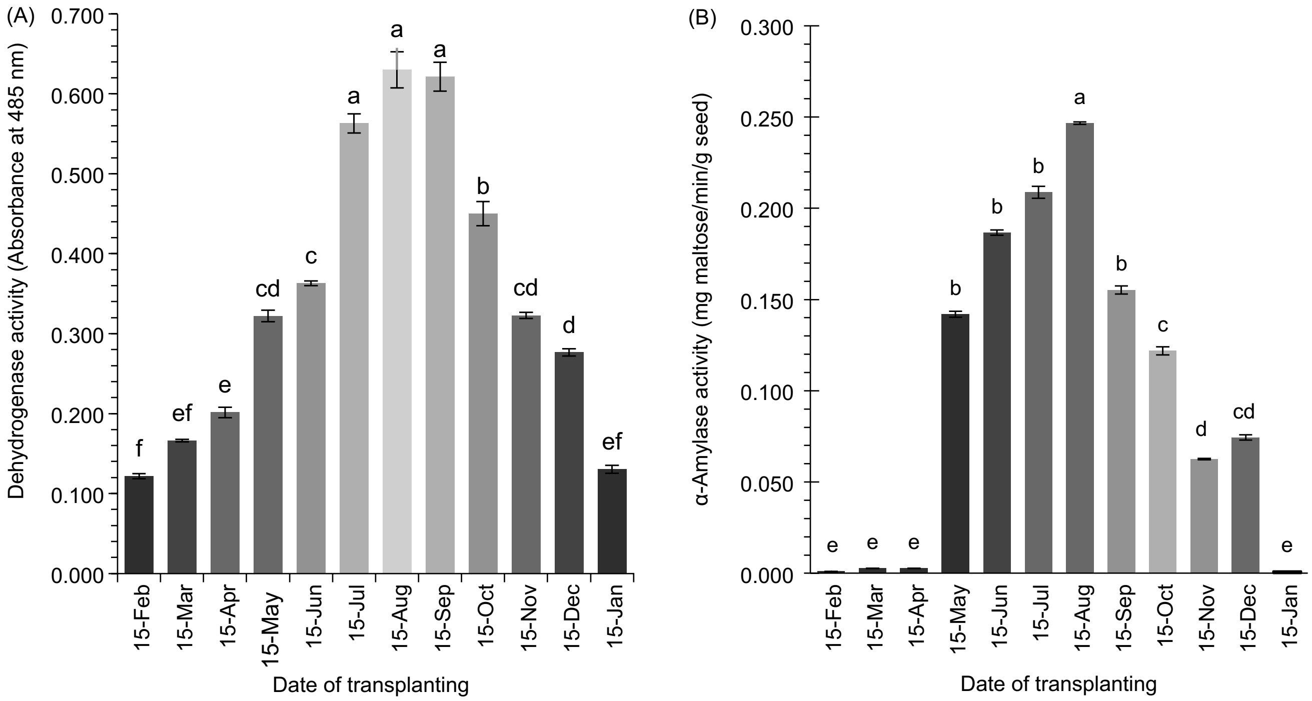

Fig. 3 Effect of year-round transplantation on (A) dehydrogenase activity and (B) α-amylase activity in African marigold cv. Punjab Gainda No. 1 (pooled data of 2021–22 and 2022–23).
Mean values in each column with the same letter are not significantly different at $p \leq 0.05$ according to Duncan's multiple range test. Bars on the graph indicate standard error computed from replications.

cell division, elongation and establishment of the seedling. The highest α-amylase activity was recorded in 15th August transplanting as the seeds obtained were fully mature with higher accumulation of storage reserves in the endosperm and thus providing ample substrate for α-amylase activity. The seeds obtained from November to May transplanting recorded the lowest α-amylase activity due to lower seed quality in terms of lower dehydrogenase activity and lesser accumulation of storage reserves that adversely affected seed germination and early seedling growth. This indicates that enzymatic activity during germination is closely linked with the quality of seed reserves accumulated during seed development, which in turn is governed by environmental conditions prevailing during the reproductive phase.

Seed storage reserves: August transplanted crop recorded the highest total soluble sugar content (4.23 mg/g seed) followed by 15th September (3.08 mg/g seed) and July (2.03 mg/g seed) transplanting (Table 2). Transplanting from 15th October to 15th April recorded progressively decreasing accumulation of total soluble sugars. Reduced accumulation of sugars in seeds has several effects. Similar reductions in assimilate accumulation under temperature stress conditions have been reported in several crops, where sub-optimal temperatures during seed development impair photosynthesis and assimilate translocation, thereby reducing seed quality (Waingankar *et al.* 2025).

Sugars provide a readily available energy source to the seeds during germination and early seedling growth. This energy reserve allows seeds to sustain metabolic processes and support growth during seedling establishment. Reduced allocation of photo-assimilates, thus, resulted in reduced sugar accumulation in seeds during seed filling, which adversely affects the seed germination and viability potential of the seed (Sehgal *et al.* 2018). Reduced carbohydrate accumulation under temperature stress conditions has also been reported to be associated with impaired metabolic activity and assimilate partitioning during seed development (Wang *et al.* 2018, Szczerba *et al.* 2021). The reduced photosynthetic activity during winter leads to reduced sugar production and consequently lesser accumulation of sugars in the seeds.

The highest starch content was recorded in 15th August transplanting followed by 15th September and 15th July transplanting (Table 2). Other transplanting dates recorded lesser starch content in the seeds. Reduced starch accumulation under temperature stress conditions has been widely reported in crops, where elevated temperatures during seed development impair starch biosynthesis through reduced activity and down regulation of key enzymes involved in starch synthesis, including soluble starch synthase and related enzymes (Yang *et al.* 2018, Lu *et al.* 2019). High temperature stress during grain filling has been shown to significantly suppress starch deposition and enzyme activity, thereby reducing seed weight and quality (Yang *et al.* 2018). Starch is a major component of marigold seed reserves; therefore, reduced starch synthesis can adversely affect both seed development and germination. Consequently, impaired starch accumulation under stress conditions may lead to compromised seed quality (Sehgal *et al.* 2018). Similar reductions in starch accumulation

Table 2 Effect of year-round transplanting on seed storage reserves of African marigold cv. Punjab Gainda No. 1 (pooled data of 2021–22 and 2022–23)

Season/Month of transplanting	Total soluble sugar (mg/g seed)	Starch content (mg/g seed)	Total soluble protein (mg/g seed)	Total free amino acid (mg/g seed)
Spring				
15th February	$0.82^{e} \pm 0.01$	$0.97^{f} \pm 0.01$	$0.21^{d} \pm 0.01$	$0.010^{c} \pm 0.01$
15th March	$0.85^{e} \pm 0.01$	$0.97^{f} \pm 0.01$	$0.22^{d} \pm 0.01$	$0.020^{c} \pm 0.01$
Summer				
15th April	$0.85^{de} \pm 0.01$	$0.96^{f} \pm 0.01$	$0.36^{d} \pm 0.01$	$0.030^{c} \pm 0.01$
15th May	$1.03^{d} \pm 0.01$	$3.75^{d} \pm 0.03$	$0.97^{c} \pm 0.02$	$0.095^{ab} \pm 0.01$
15th June	$1.13^{d} \pm 0.02$	$3.94^{d} \pm 0.04$	$0.99^{c} \pm 0.01$	$0.090^{ab} \pm 0.01$
Rainy				
15th July	$2.03^{c} \pm 0.02$	$4.42^{c} \pm 0.04$	$3.12^{b} \pm 0.05$	$0.100^{ab} \pm 0.01$
15th August	$4.23^{a} \pm 0.05$	$7.52^{a} \pm 0.04$	$4.30^{a} \pm 0.03$	$0.125^{a} \pm 0.01$
Autumn				
15th September	$3.08^{b} \pm 0.01$	$6.33^{b} \pm 0.02$	$1.31^{c} \pm 0.16$	$0.085^{b} \pm 0.01$
15th October	$0.97^{de} \pm 0.01$	$3.93^{d} \pm 0.05$	$0.95^{c} \pm 0.01$	$0.035^{c} \pm 0.01$
Winter				
15th November	$0.98^{de} \pm 0.02$	$2.67^{e} \pm 0.02$	$0.45^{d} \pm 0.01$	$0.010^{c} \pm 0.01$
15th December	$0.94^{de} \pm 0.04$	$1.03^{f} \pm 0.01$	$0.45^{d} \pm 0.02$	$0.020^{c} \pm 0.01$
15th January	$0.82^{e} \pm 0.01$	$0.98^{f} \pm 0.01$	$0.40^{d} \pm 0.01$	$0.015^{c} \pm 0.01$

Mean values in each column with the same letter are not significantly different at $p \leq 0.05$ according to Duncan's multiple range test. Values are given as mean ± SE computed from triplicates.

under temperature stress have been reported in field crops, where altered enzymatic activity and assimilate partitioning during seed development limit storage reserve deposition (Thenveettil *et al.* 2024, Yang *et al.* 2024).

August transplanted crop recorded the highest total soluble protein content. Transplanting from 15th October to 15th April recorded comparatively lesser accumulation of total soluble proteins (Table 2). Higher content of total soluble proteins was obtained when transplanting was done on 15th August and 15th July as crop transplanted during this period experienced optimum growing conditions during vegetative as well as seed filling period ensuring optimum seed viability and germination potential. Crop transplanted in winter months as well as summer months recorded lesser content of total soluble proteins due to unfavourable environmental conditions during vegetative and reproductive phases of crop. Wang and Liu (2021) also recorded similarly reduced accumulation of proteins in wheat seeds due to heat stress.

The highest content of total free amino acids in seeds was recorded in 15th August transplanting which was statistically at par with 15th May and 15th July transplanting (Table 2). Transplanting on other dates recorded lesser content of total free amino acids. The seeds obtained from winter season transplanting accumulated lesser amino acids due to cold stress which hampers the storage proteins, amino acids and mineral accumulation in seeds. Transport constraints to the seeds could possibly be the cause of the decline in minerals and amino acids in the seeds under chilling stress. Similar reductions in amino acid and protein accumulation under temperature stress have been reported, primarily due to impaired metabolic activity and disruption of nitrogen assimilation pathways during seed development (Thenveettil *et al.* 2024, Yang *et al.* 2024).

Correlation studies: A bivariate Pearson correlation analysis was conducted (Fig. 4) between seed weight, germination and quality characteristics in Punjab Gainda No. 1 to calculate correlation coefficient 'r', measuring the strength and direction of linear relationships between these seed quality attributes. The study found a strong and positive correlation between the seed quality parameters. A significant link ($p \leq 0.001$) was found between the weight of 1000 seeds and their germination rate (r = 0.98), dehydrogenase activity (r = 0.91), total soluble sugars (r = 0.88), starch (r = 0.95), α-amylase activity (r = 0.89), total soluble proteins (r = 0.86) and total free amino acids (r = 0.90). This reflects the strong interdependence of physiological and biochemical processes governing seed development and quality. There was a strong link ($p \leq 0.001$) between the amount of starch in seeds and the storage and use of food reserves like soluble sugars (r = 0.88), soluble proteins (r = 0.81) and free amino acids (r = 0.86). Furthermore, a strong correlation was also found with the enhanced mobilisation of storage reserves in the terms of seed viability parameters such as dehydrogenase (r = 0.94) and α-amylase activity (r = 0.89). As a result, increased activity of α-amylase and dehydrogenase can also result in improved utilisation of food reserves, which, as a consequence, enhances the germination percentage and viability indices in seeds (Fig. 2 and 3). Also, these enzymes affect many developmental biochemical pathways that help seeds properly fill out and mature, which leads to heavier seeds. The heavier seed weight is strongly linked to and might be the cause of better seed germination, seed viability and germination rates (Table 1 and Fig. 2) in the August transplanted African marigold cv. Punjab Gainda No 1. These inferences led us to conclude that improvement in one of these interconnected traits will result in potentially enhanced overall seed quality and, ultimately, plant performance of this commercial crop.

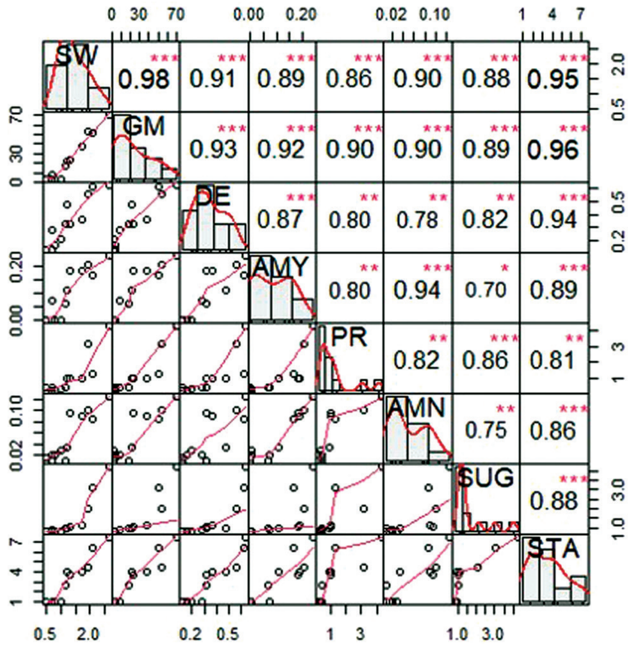

Fig. 4 Correlation plot analysis between seed weight, germination and quality parameters.
SW, 1000 seed weight; GM, Germination percentage; DE; Dehydrogenase activity; PR, Total soluble proteins; SUG, Total soluble sugars; STA, Starch; AMY, α-amylase activity; AMN, Total free amino acids).
Significant at $*p \leq 0.05$ level; $**p \leq 0.01$ level; $***p \leq 0.001$ level.

These results collectively indicate that transplanting time regulates seed quality through its influence on environmental conditions during seed development, which subsequently governs assimilate accumulation, enzymatic activity and overall seed viability. Mid-July to mid-September transplanted crops exhibited higher quality due to favourable environmental conditions supporting vegetative growth and seed filling with mid-August transplanting yielding the highest seed yield and optimum seed quality. Apparently, our study concluded that African marigold should be transplanted on 15th August for obtaining optimum seed yield and seed quality parameters under the climatic conditions of northern plains of India.

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