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Optimizing Planting Time and Growing Environments for Enhanced Seed Yield and Quality in Marigold (*Tagetes erecta* L.) Under Mid-hill Region of Himachal Pradesh

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ABSTRACT

The rising demand for marigold (Tagetes erecta L.) seeds in India, driven by large-scale cultivation, necessitates the development of effective technologies to enhance seed yield and quality. A study was conducted to optimize planting time and growing conditions for marigold seed production. The experiment was arranged in a randomized block design with five planting dates staggered at 15-day intervals, evaluated under open field and naturally ventilated polyhouse conditions using two marigold cultivars, 'Pusa Narangi Gainda' and 'Pusa Basanti Gainda'. Significant effects of planting dates, growing environments, and cultivars were observed on various seed parameters. The results revealed that planting on 10th July under open field conditions with the cultivar 'Pusa Basanti Gainda' produced superior quality seeds, achieving the highest seed yield per plant (19.92 g) and per square meter (171.92 g), making it the most suitable option for commercial seed production. Additionally, both cultivars demonstrated satisfactory seed yield under open field conditions up to August planting. These findings underscore the importance of optimizing planting time and selecting appropriate growing environments to enhance the quality and quantity of marigold seed production. Thus, regulating planting time under a congenial growing environment can significantly enhance the quality of seed production.

Keywords: *Cultivars, Economics, Growing Environment, Marigold, Naturally Ventilated Polyhouse, Seed Yield, Staggered Planting*

INTRODUCTION

Marigold (*Tagetes spp. L.*), belonging to the Asteraceae family, is native to the Americas, particularly Mexico [1]. The genus *Tagetes* comprises approximately 55 species [2], with *Tagetes erecta L.* and *Tagetes patula L.* being the most economically important and widely cultivated species. Marigold is a prominent loose-flower crop in India, valued for its ease of cultivation, high resilience, short juvenile phase, prolific and extended flowering period, vibrant colors, attractive shapes and sizes, and excellent post-harvest quality. It is among the most widely cultivated flower crops in tropical and subtropical regions worldwide for ornamental purposes [3]. India's diverse agro-climatic conditions are highly conducive to marigold cultivation, enabling its widespread production across numerous states. Marigold is the leading traditional loose-flower crop in India, occupying an area of 80,980 hectares with a production of 941.46 metric tons [4].

The decline in productivity is primarily attributed to the shortage of high-quality seeds and the lack of improvement in F1 hybrids for cultivation. Traditional marigold varieties, which are low-yielding and genetically impure, can be replaced with emerging high-yielding cultivars. Ensuring seed quality is critical, as there is a shortage of quality seeds due to the absence of standardized seed production practices. Flower seed production is gaining popularity in India due to its significant export potential, offering 2.5 to 3 times higher profits compared to other crops in Punjab [5]. Moreover, marigold seed production offers a cost-effective opportunity to tap into the growing export market, particularly in North India. As marigold is cultivated year-round across the country, ensuring the availability of quality seeds becomes crucial. In Himachal Pradesh, marigold seed production holds considerable profit potential and could help meet domestic seed demand. However, there is limited information on optimal seed production practices in the mid-hill region of Himachal Pradesh.

In marigold cultivation, planting time plays a critical role in determining both the quality and quantity of seed production [6]. The regional weather conditions and topographical characteristics significantly influence the optimal planting time for flower crops. The diverse agro-climatic conditions across the Indian subcontinent lead to considerable variation in plant development and flowering period, making it challenging to define ideal planting time at the national level. Therefore, to achieve optimal growth, flowering and seed yield in marigold, it is essential to standardize region-specific planting schedules. Given the crop's importance to farmers, identifying the ideal planting time and favourable growing conditions for commercial seed production is crucial. This study aims to evaluate the effects of staggered planting and varying growing environments on seed attributes of the marigold cultivars 'Pusa Narangi Gainda' and 'Pusa Basanti Gainda'.

MATERIALS AND METHODS

The study was conducted from June 2020 to February 2021 at the Experimental Farm of the Department of Floriculture and Landscape Architecture, Dr. Yashwant Singh Parmar University of Horticulture and Forestry, Nauni, Solan, Himachal Pradesh.

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The experimental site is located at an altitude of 1276 meters above mean sea level, with geographic coordinates of 30°52'02"N latitude and 77°11'30"E longitude. The region falls within the mid-hill zone of Himachal Pradesh, characterized by a sub-temperate to sub-tropical climate, experiencing mild summers and cold winters.

The experiment was conducted using a factorial randomized block design with three replications, using two marigold cultivars, 'Pusa Narangi Gainda' (V_1) and 'Pusa Basanti Gainda' (V_2). Healthy, uniform seedlings at the 4-6 leaf stage were transplanted at a spacing of 30 cm × 30 cm across five planting dates: 10th July (D_1), 25th July (D_2), 10th August (D_3), 25th August (D_4), and 10th September (D_5). The study was carried out under two environmental conditions: open field (E_1) and naturally ventilated polyhouse (E_2). Temperature, a key factor influencing marigold growth and flowering, was found to be 4˚C more acute in the polyhouse compared to open field conditions (Fig. 1). Standard crop management practices, including irrigation, weeding, pinching, staking, and pest control, were followed throughout the experiment. Data were collected on various seed parameters, including days to seed head maturity, number of seeds per head, seed weight per head (g), seed yield per plant (g) and seed yield per square meter (g), in accordance with standardized research protocols.

Statistical analysis of the data for various seed parameters was performed using Analysis of Variance (ANOVA) as outlined by [7] through OPSTAT [8]. The significance of treatment effects was assessed using the F-test and comparisons were made based on the critical differences (CD) at the 5% level of significance. Additionally, regression analysis was computed between various parameters and yield using Microsoft Excel software [9].

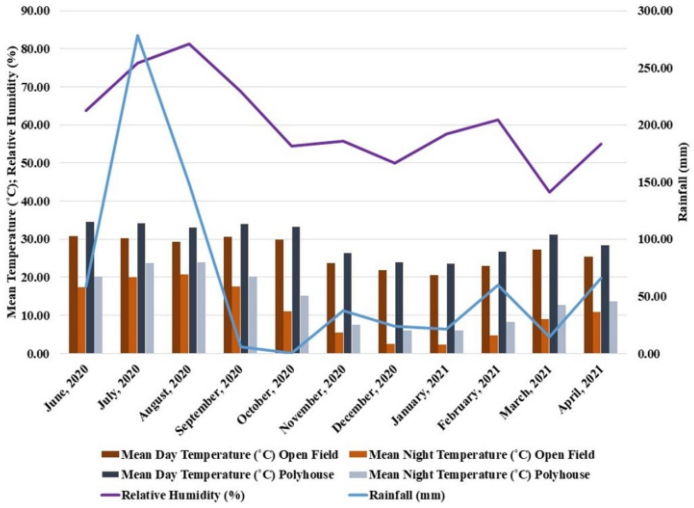

Fig. 1. Meteorological data during the crop period (June, 2020 - April, 2021)

RESULTS AND DISCUSSION

During the experiment, data were recorded on various seed parameters of marigold (*Tagetes erecta L.*), including days to seed head maturity, number of seeds per head, seed weight per head (g), seed yield per plant (g), and seed yield per square meter (g). The results indicated that different planting dates significantly affected the seed attributes of marigold cultivars 'Pusa Narangi Gainda' and 'Pusa Basanti Gainda' under both open field and naturally ventilated polyhouse conditions (Table 1). The earliest seed heads matured in the crop planted on 10th September (137.97 days), whereas the earliest planting date (10th July) took the longest time to mature seed heads (184.17 days). Crops grown under open field conditions produced seed heads earlier (142.65 days) compared to those grown in the polyhouse (180.17 days). Additionally, 'Pusa Basanti Gainda' showed earlier seed head maturity (159.53 days) than 'Pusa Narangi Gainda' (163.29 days) (Table 1). These differences can be attributed to the cooler temperatures and higher humidity (Fig. 1) during head formation, which delayed maturation in crops planted later. These findings are consistent with previous research [10], which reported a delay in full maturity in the cosmos when planted in July and August compared to May.

Planting on 10th July resulted in the maximum number of seeds per head (220.37), along with greater seed weight per head (0.53 g) and test weight (2.43 g). In terms of growing environment, the maximum number of seeds per head (205.13), along with greater seed yield per head (0.42 g) and test weight (1.99 g), was observed under open field conditions. Among the two marigold cultivars, Pusa Narangi Gainda produced more seeds per head (202.94), whereas Pusa Basanti Gainda recorded higher seed yield per head (0.41 g) and test weight (1.99 g). These differences could be attributed to increased flower size, which resulted in larger sized heads with a maximum number of seeds. Additionally, the ideal temperature during the active growth period, along with a longer reproductive phase and effective flower pollination facilitated by enhanced pollinator activity, contributed to the maximum seed count per head. The increased light intensity and favorable temperatures during the blooming and seed maturation period in the 10th July planting also likely favoured better seed filling, resulting in bold seeds. The longer grain filling period may have further contributed to higher seed weight and improved grain filling. Similar results were documented in earlier studies [6], highlighting that marigold planted in July produced the highest number of seeds per head. Furthermore, [11] and [12] also recorded the greatest seed yield per head with early planting of marigold. Additionally, it is also reported that *Antirrhinum majus* L. plants shown a maximum number of seeds per pod under protected cultivation [13].

Table 1: Effect of planting dates, growing environment and cultivars on seed parameters.

Particulars	Days taken for seed head maturity (days)	Number of seeds per head	Seed yield per head (g)	1000 seed weight (g)	Seed yield per plant (g)	Seed yield per square meter (g)
Main effect of Planting Dates (D)						
D_1	184.17	220.37	0.50	2.43	16.71	145.38
D_2	178.06	201.00	0.41	2.08	11.47	98.73
D_3	157.26	190.04	0.36	1.72	7.52	62.15
D_4	149.58	187.62	0.35	1.60	5.59	45.24
D_5	137.97	181.08	0.32	1.55	3.42	27.96
Mean	**161.41**	**196.02**	**0.39**	**1.87**	**8.94**	**75.89**
SE(m) ±	**0.38**	**1.59**	**0.01**	**0.03**	**0.42**	**3.87**
CD (0.05)	**1.14**	**4.55**	**0.03**	**0.09**	**1.19**	**11.11**
Main effect of Growing environment (E)						
E_1	142.65	205.13	0.42	1.99	9.90	81.75
E_2	180.17	186.91	0.36	1.75	7.98	70.03
Mean	**161.41**	**196.02**	**0.39**	**1.87**	**8.94**	**75.89**
SE(m) ±	**0.25**	**1.00**	**0.01**	**0.02**	**0.26**	**2.45**
CD (0.05)	**0.72**	**2.88**	**0.02**	**0.06**	**0.75**	**7.02**
Main effect of cultivars (V)						
V_1	163.29	202.94	0.36	1.76	8.35	71.79
V_2	159.53	189.11	0.41	1.99	9.53	80.00
Mean	**161.41**	**196.02**	**0.39**	**1.87**	**8.94**	**75.89**
SE(m) ±	**0.25**	**1.00**	**0.01**	**0.02**	**0.26**	**2.45**
CD (0.05)	**0.72**	**2.88**	**0.02**	**0.06**	**0.75**	**7.02**

D_1-10th July, D_2-25th July, D_3-10th August, D_4-25th August, D_5-10th September
E_1-Open condition, E_2-Naturally ventilated polyhouse condition
V_1-Pusa Narangi Gainda, V_2-Pusa Basanti Gainda

The highest seed production per plant (16.71 g) and per square meter (145.38 g) was observed with the 10th July planting, while the lowest seed yield was recorded with the 10th September planting (Table 1). In terms of growing environment, the marigold crop planted in the open field produced higher seed yield per plant (9.90 g) and per square meter (81.75 g) compared to the naturally ventilated polyhouse. Among the cultivars, Pusa Basanti Gainda produced a higher seed yield per plant (9.53 g) and per square meter (80 g) than Pusa Narangi Gainda. The highest yield observed with the 10th July planting can be attributed to an increased number of heads per plant, along with a maximum number of seeds per head. These findings are consistent with previous research [6], which reported maximum seed yield per plant in July plantings. Furthermore, [11] also recorded the highest seed yield per plant in early-planted marigold crops. Similar results have been reported for other annuals, including sweet william [14], garland chrysanthemum [15], satin flower [16], candytuft [17], and snapdragon [18]. Among the cultivars, Pusa Basanti Gainda matured its seed heads earlier than Pusa Narangi Gainda. Additionally, Pusa Narangi Gainda produced more seeds per head, while Pusa Basanti Gainda exhibited higher seed yield per head, test weight, seed yield per plant and per square meter. The variation in seed quality and yield traits across cultivars may be attributed to their genetic traits and growth and development rates [19].

Table 2: Interaction effect of planting dates and growing environment (D×E), planting dates and marigold cultivars (D×V) and growing environment and marigold cultivars (E×V) on seed parameters.

Particulars	Days taken for seed head maturity (days)	Number of seeds per head	Seed yield per head (g)	1000 seed weight (g)	Seed yield per plant (g)	Seed yield per square meter (g)
Interaction between planting dates and growing environment (D×E)						
D_1E_1	159.27	236.64	0.57	2.56	19.34	168.53
D_1E_2	209.07	202.18	0.44	2.30	14.08	122.22
D_2E_1	153.82	211.81	0.46	2.14	12.21	100.86
D_2E_2	202.31	190.18	0.36	2.02	10.73	96.60
D_3E_1	143.20	196.26	0.39	1.83	7.65	64.14
D_3E_2	171.32	183.83	0.34	1.60	7.39	60.16
D_4E_1	134.93	192.28	0.34	1.81	6.43	45.41
D_4E_2	164.22	182.96	0.35	1.39	4.76	45.07
D_5E_1	122.02	186.68	0.32	1.63	3.90	29.84
D_5E_2	153.91	175.49	0.32	1.46	2.95	26.09
Mean	**161.41**	**196.02**	**0.39**	**1.87**	**8.94**	**75.89**
SE(m) ±	**0.56**	**2.50**	**0.02**	**0.05**	**0.59**	**5.48**
CD (0.05)	**1.61**	**7.17**	**0.04**	**0.13**	**1.69**	**15.71**
Interaction between planting dates and cultivars (D×V)						
D_1V_1	187.87	232.10	0.47	2.30	15.74	139.78
D_1V_2	180.47	208.64	0.53	2.56	17.68	150.97
D_2V_1	180.38	206.03	0.37	1.94	11.16	95.91
D_2V_2	175.74	195.96	0.45	2.21	11.78	101.55

D_3V_1	162.22	196.97	0.37	1.63	7.17	59.55
D_3V_2	152.30	183.12	0.36	1.80	7.86	64.76
D_4V_1	150.27	194.79	0.31	1.40	5.04	42.18
D_4V_2	148.88	180.45	0.39	1.79	6.15	48.30
D_5V_1	135.69	184.79	0.29	1.50	2.67	21.52
D_5V_2	140.24	177.38	0.35	1.59	4.18	34.41
Mean	**161.41**	196.02	**0.39**	**1.87**	**8.94**	**75.89**
SE(m) ±	**0.56**	**2.50**	**0.02**	**0.05**	**0.59**	**5.48**
CD (0.05)	**1.61**	**7.17**	**0.04**	**0.13**	**NS**	**NS**
Interaction between growing environment and cultivars (E×V)						
E_1V_1	143.43	210.25	0.38	1.81	9.21	77.69
E_1V_2	141.86	200.01	0.46	2.17	10.60	65.87
E_2V_1	183.14	195.62	0.35	1.70	7.50	85.81
E_2V_2	177.19	178.21	0.37	1.81	8.46	74.18
Mean	**161.41**	**196.02**	**0.39**	**1.87**	**8.94**	**75.89**
SE(m) ±	**0.35**	**1.58**	**0.01**	**0.03**	**0.37**	**3.47**
CD (0.05)	**1.02**	**4.54**	**0.03**	**0.08**	**NS**	**NS**

D_1-10th July, D_2-25th July, D_3-10th August, D_4-25th August, D_5-10th September,
E_1-Open condition, E_2-Naturally ventilated polyhouse condition; V_1-Pusa Narangi Gainda, V_2-Pusa Basanti Gainda

Table 3. Interaction effect of planting dates, growing environment and cultivars on seed parameters.

Particulars	Days taken for seed head maturity (days)	Number of seeds per head	Seed yield per head (g)	1000 seed weight (g)	Seed yield per plant (g)	Seed yield per square meter (g)
$D_1E_1V_1$	164.51	244.07	0.53	2.54	18.76	165.14
$D_1E_1V_2$	154.02	233.22	0.61	2.58	19.92	171.92
$D_1E_2V_1$	211.22	220.13	0.42	2.06	12.71	114.42
$D_1E_2V_2$	206.91	184.07	0.45	2.54	15.45	130.02
$D_2E_1V_1$	155.07	214.33	0.39	1.92	11.75	96.72
$D_2E_1V_2$	152.56	209.29	0.53	2.35	12.67	105.00
$D_2E_2V_1$	205.68	197.73	0.34	1.96	10.57	95.10
$D_2E_2V_2$	198.93	182.63	0.37	2.07	10.90	98.10
$D_3E_1V_1$	147.30	202.78	0.35	1.58	7.26	62.04
$D_3E_1V_2$	139.11	189.73	0.43	2.09	8.03	66.24
$D_3E_2V_1$	177.14	191.16	0.38	1.68	7.08	57.05
$D_3E_2V_2$	165.50	176.51	0.29	1.51	7.70	63.27
$D_4E_1V_1$	135.13	200.16	0.31	1.53	5.44	42.06
$D_4E_1V_2$	134.73	184.40	0.38	2.08	7.43	48.76
$D_4E_2V_1$	165.42	189.42	0.31	1.28	4.64	42.29
$D_4E_2V_2$	163.03	176.50	0.40	1.50	4.87	47.84
$D_5E_1V_1$	115.16	189.93	0.30	1.49	2.83	22.53
$D_5E_1V_2$	128.88	183.42	0.34	1.77	4.96	37.15
$D_5E_2V_1$	156.22	179.64	0.29	1.51	2.50	20.50
$D_5E_2V_2$	151.60	171.33	0.36	1.41	3.39	31.67
Mean	**161.41**	**196.02**	**0.39**	**1.87**	**8.94**	**75.89**
SE(m) ±	**0.79**	**3.18**	**0.02**	**0.06**	**0.83**	**7.76**
CD (0.05)	**2.28**	**9.09**	**0.06**	**0.18**	**NS**	**NS**

D_1-10th July, D_2-25th July, D_3-10th August, D_4-25th August, D_5-10th September
E_1-Open condition, E_2-Naturally ventilated polyhouse condition
V_1-Pusa Narangi Gainda, V_2-Pusa Basanti Gainda

The interaction effects between planting date and marigold cultivar (D×V), planting date and growing environment (D×E) and growing environment and marigold cultivar (E×V) were found to significantly influence seed head maturity time, number of seeds per head, seed yield per head and 1000 seed weight (Table 2). Significant differences were also observed for the interaction among planting dates, growing environments and cultivars (Tables 2 & 3). The earliest seed head maturity was observed from the 10th September planting under open field conditions in Pusa Narangi Gainda (115.16 days). The 10th July planting under open field conditions with Pusa Narangi Gainda recorded the highest number of seeds per head (244.07). The 10th July planting of Pusa Basanti Gainda under open field conditions produced the highest seed weight per head (0.64 g) and 1000 seed weight (2.58 g). However, no significant differences were observed among the interaction effects for seed yield per plant or per square meter. The highest seed yield per plant (19.92 g) and per square meter (171.92 g) was recorded from the 10th July planting under open field conditions with Pusa Basanti Gainda, this was followed by the 10th July planting under open field conditions with Pusa Narangi Gainda, which yielded 18.76 g of seed per plant and 765.14 g of seed per square meter. These results can be attributed to the combined effect of optimal planting time under favourable growing conditions, coupled with the inherent traits of the marigold cultivars throughout the cropping period. These factors facilitated luxuriant plant growth and a swift transition to the reproductive phase, ultimately enhancing seed yield.

The regression analysis conducted between various seed attributes and seed yield revealed a range of correlations, from strong to weak, among the parameters (Fig. 2). A strong correlation was observed between 1000 seed weight, seed weight per head and number of seeds per head, with R^2 values of 0.823, 0.712, and 0.588, respectively. In contrast, the days required for seed head maturity showed a weak correlation with seed yield per plant, with an R^2 value of 0.196. Thus, Regression analysis emphasized the significant contributions of 1000 seed weight, seed weight per head, and number of seeds per head in determining marigold seed yield [20, 21].

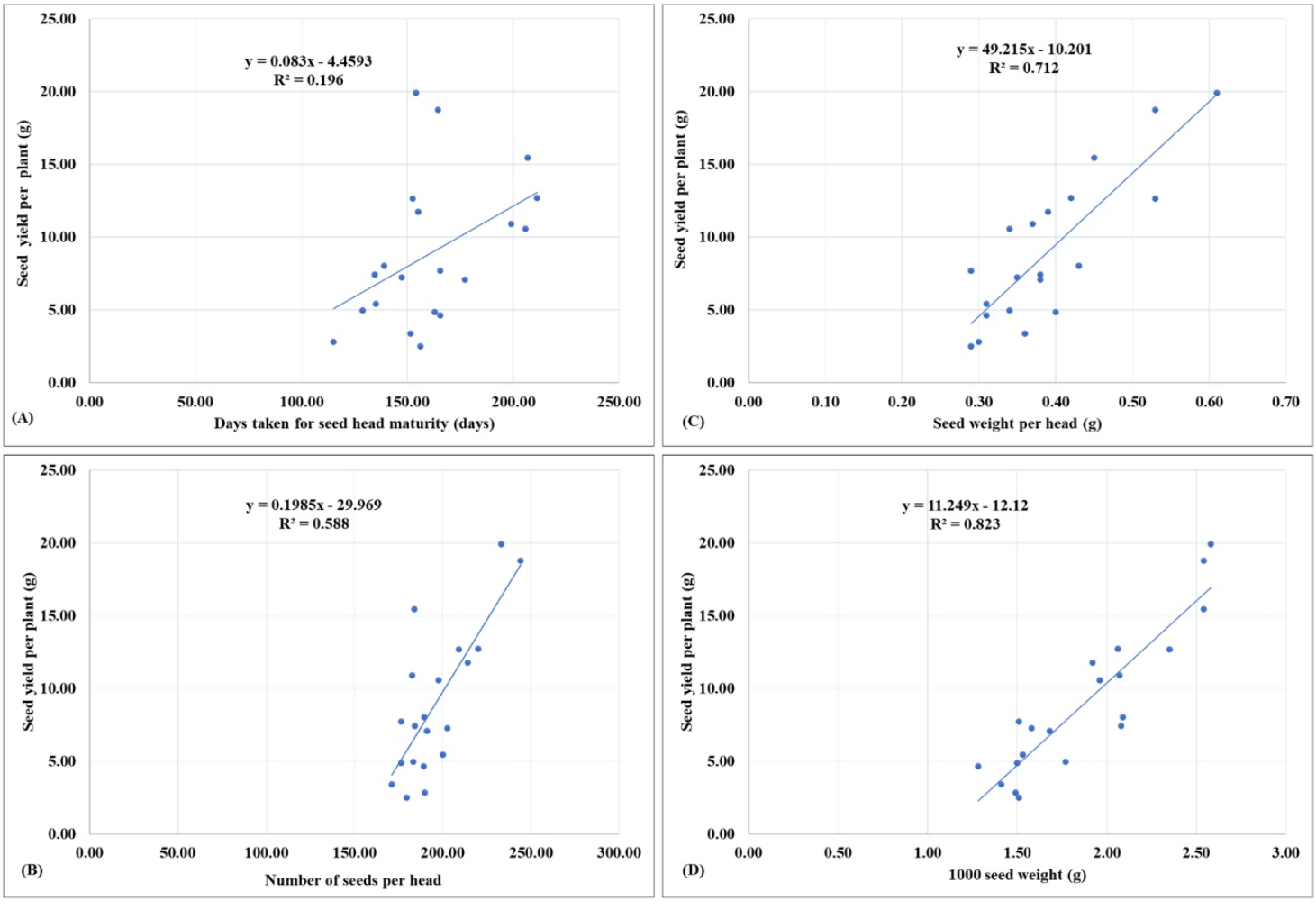

Fig. 2. Regression analysis of various seed attributes with yield attributes of marigold cultivars as influenced by staggered planting and growing environments.

CONCLUSION

The impact of different marigold cultivars, through staggered planting under varying environmental conditions, was significant on seed attributes. Based on the data, it can be concluded that planting on 10th July under open field conditions with Pusa Basanti Gainda is the most effective strategy for maximizing marigold seed yield. This optimal planting schedule offers farmers the potential for satisfactory returns. Additionally, planting both Pusa Narangi Gainda and Pusa Basanti Gainda from 10th July to 25th August under open field and naturally ventilated polyhouse conditions could prove to be a profitable approach for quality seed production in the mid-hill region of Himachal Pradesh. This study highlights that adjusting planting times, selecting the appropriate growing environment, and choosing the right marigold cultivar can significantly enhance crop growth, flowering, and seed yields, providing farmers with opportunities for increased profitability.

FUTURE SCOPE OF STUDY

Based on the findings of the present study, future research could focus on extending trials to diverse agro-climatic zones across India to develop region-specific recommendations.
Investigation into advanced seed production technologies, and breeding programs for enhanced seed traits.
Additionally, developing integrated pest management protocols specifically for seed production and conducting economic analyses would address critical knowledge gaps in marigold seed production. These efforts would significantly enhance the commercial viability and sustainability of marigold seed production to meet the growing national demand.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest for the publication of the manuscript.

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