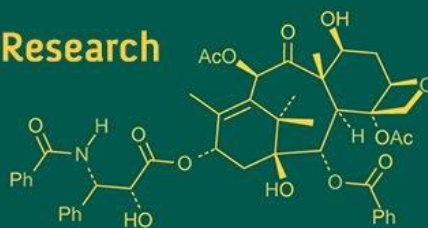


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Genetic and environmental contributions to variation in seed quality, growth, and yield in different genotypes of chickpea (*Cicer arietinum* L.) through fortification techniques

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Abstract

The present investigation entitled “Genetic and Environmental Contributions to Variation in Seed Quality, Growth, and Yield in Different Genotypes of Chickpea (*Cicer arietinum* L.) Through Fortification Techniques” was conducted during the *Rabi* season of 2024-25 at the Agricultural Research Farm, Prof. Rajendra Singh (Rajju Bhaiya) University, Naini, Prayagraj, to evaluate the effect of GA₃ 0.5% and PEG₆₀₀₀ 0.5% on the performance chickpea genotypes. Significant differences were observed among the twelve chickpea genotypes and treatments for various growth and yield parameters. Days to 50% flowering ranged from 75.33 days in LOCAL+PEG₆₀₀₀ @0.05% to 80.33 days in AVRODHI. Plant height at 30 DAS was highest in DNA334 (31.73 cm) and lowest in RADHEY+PEG6000 @0.05% (18.13 cm). Similarly, plant height at 60 DAS ranged from 21.80 cm to 36.73 cm, and at 90 DAS from 53.03 cm (Pusa 362) to 60.40 cm (Pusa362+GA₃ @0.05%). The number of pods per plant was maximum in AVRODHI+GA₃ @0.05% (65.33), followed by Pusa362+GA₃ @0.05% (63.93), and minimum in LOCAL (41.97). Branches per plant ranged from 3.97 (DNA334) to 6.07 (LOCAL+PEG6000 @0.05%). In terms of maturity, genotypes matured between 121.67 days (DNA334+GA₃ @0.05%) and 130 days (Pusa 362). Seed yield per plot was highest in AVRODHI (1.50 kg) and lowest in RADHEY (0.81 kg). The biological yield ranged from 1.24 kg to 2.02 kg, with the highest value again recorded in AVRODHI. The 100-seed weight was highest in Pusa362+GA₃ @0.05% (27.97 g) and lowest in RADHEY+PEG6000 @0.05% (20.23 g). The harvest index varied from 59.27% (DNA334) to 77.42% (LOCAL), while seed yield per plant was highest in AVRODHI+GA₃ @0.05% (15.97 g).

Keywords: Chickpea, genotype, environmental, fortification, GA₃, PEG₆₀₀₀

Introduction

Chickpea (*Cicer arietinum* L.) is a self-pollinated true diploid (2n=2x=16) cool season leguminous crop that ranks second among food grain legumes in the world after common bean, and grown in a wide range of environments in over 50 countries in subtropical and temperate regions of the world, mainly in the Indian subcontinent, West Asia, North Africa, the Americas and Australia (FAOSTAT, 2011) ^[1].

There are two major types of chickpea distinguished by seed-size, shape and color. One, desi-type is characterized by relatively smaller seeds of angular shape with dark seed coat, whereas other Kabuli type is characterized by large owl/ram-head-shaped seeds with beige-colored seed coat. Kabuli-type chickpea is considered more economically important as it receives higher market price than desi-type. (Agarwal *et al.* 2012.) ^[1].

It is excellent source of iron (Fe), zinc (Zn), phosphorus (P), magnesium (Mg), calcium (Ca), and potassium (K). Biofortification efforts aim to enhance Fe and Zn concentrations to combat micronutrient malnutrition (Upadhyaya *et al.* 2016) ^[45]. Vitamins: Contains significant amounts of folate (vitamin B9), thiamine (B1), riboflavin (B2), niacin (B3), and vitamin K. Bioactive Compounds: Abundant in phenolic compounds (flavonoids, phenolic acids) with antioxidant properties, phytosterols, carotenoids (lutein, zeaxanthin), and saponins, all contributing to potential health benefits like reduced risk of

cardiovascular disease, diabetes, and certain cancers (Segev *et al.* 2010; Yang *et al.* 2020) [40, 50]. Low Glycaemic Index (GI): The combination of protein, fiber, and complex carbohydrates results in a low GI, making chickpea beneficial for blood glucose management. despite its resilience, chickpea production faces significant constraints: Abiotic Stresses: Drought Terminal drought is a primary yield limiter in rainfed environments. Research focuses on root traits, early maturity, and physiological mechanisms (Purushothaman *et al.*, 2017) [33]. Heat Stress: Increasingly problematic with climate change, causing flower/pod abortion and reduced seed quality. Screening for heat tolerance and identifying thermotolerant genotypes is critical (Devasirvatham *et al.* 2012; Kaushal *et al.* 2013) [9, 20]. Salinity: Limits cultivation in affected areas. Identifying salt-tolerant germplasm and understanding mechanisms is ongoing (Vadez *et al.* 2012) [46]. Cold/Frost: Susceptibility during seedling and flowering stages limits early sowing or cultivation in colder regions.

Chickpea is cultivated across diverse agro-climatic zones, predominantly in semi-arid tropical and subtropical regions. According to FAOSTAT (2023) [12], global production of dry chickpeas exceeded 17 million tons in 2021, with India dominating production (contributing over 70% of the global total), followed by Turkey, Pakistan, Australia, Myanmar, Ethiopia, Russia, and Canada. Major exporters include Australia, Russia, Mexico, and Argentina.

Environments profoundly influence chickpea growth, seed quality, and overall yield. Variance partitioning in multi-environment trials highlighted that environmental effects accounted for approximately 25.8% of the variation in grain yield across diverse regions (Khan *et al.* 2024) [21]. This underscores the importance of genotype $\times$ environment (G $\times$ E) interactions, which are crucial for assessing stability and performance across different agroecological zones. Breeding efforts focusing on traits like drought tolerance-via QTL mapping, marker-assisted selection, and genomic tools—have facilitated the development of more resilient genotypes adapted to stress-prone environments (Guo *et al.* 2024; Maphosa *et al.* 2020) [16, 28].

Fortification techniques—ranging from agronomic biofortification with fertilizers or microbial inoculants to seed treatments—offer promising strategies to further improve chickpea seed quality and yield. For example, seed priming combined with biofertilizer application (e.g.,

Rhizobium inoculation plus hydropriming) has been shown to significantly enhance traits such as plant height, pod number, seed weight, germination, and vigour index (Sarvjeet *et al.* 2017) [39]. Vermi-fortification—through incorporation of vermicompost in potting media—has also demonstrated positive effects on seedling growth and physiological health (Yadav *et al.* 2015) [49]. Moreover, integrated genomic approaches for biofortification, including QTL mapping and association analyses for nutrient traits like protein, iron, and zinc concentrations, are showing potential for breeding nutritionally superior chickpea varieties (Tripathi *et al.* 2022; Diapari *et al.* 2014) [3, 10, 44].

2. Material and Methods

The present study, titled “Genetic and Environmental Contributions to Variation in Seed Quality, Growth, and Yield in Different Genotypes of Chickpea (*Cicer arietinum* L.) Through Fortification Techniques.” was conducted during the Rabi season of 2024-25 at the Agricultural Research Field, Department of Genetics and Plant Breeding, Prof. Rajendra Singh (Rajju Bhaiya)

University, Naini, Prayagraj, using a Randomized Block Design (RBD) with three Replications. Comprising of six treatments and six control.

The experiment was designed to evaluate the effect of fortification with PEG₆₀₀₀ and GA₃ on different yield and growth parameters of chickpea viz., DAS to 50% Flowering, Plant height 30 DAS, Plant height 60 DAS, Plant height 90 DAS, No. of pod per plant, No. of branches per plant, DAS to maturity, Seed yield per plot (kg), Biological yield (kg), 100 Seed weight (g), Harvest index (%), Seed yield per plant (g). Field Experimentation mean performance and Analysis of variance was analysed statistically using the technique designated by Panse and Sukhatme (1967) [32].

Treatment Details

- PUSA362+GA₃@0.05%, (T₇)
- DNA334+GA₃ @0.05%, (T₈)
- AVRODHI+GA₃@0.05% (T₉)
- HIMMAT+PEG₆₀₀₀@0.05%(T₁₀)
- RADHEY+PEG₆₀₀₀@0.05%(T₁₁)
- LOCAL+ PEG₆₀₀₀@0.05%(T₁₂)



Fig 1: Field prepration and seed sowing. **Fig 2:** With advisors sir after field visit



Fig 3: Harvesting of chickpea after observation of all pre harvest data.

3. Result and Discussion

The results presented in this chapter comprised different aspects undertaken during the present study on “Genetic and environmental contributions to variation in seed quality, growth, and yield in different genotypes of chickpea (*Cicer arietinum* L.) Through fortification techniques.” These aspects are:

- Effect of hormonal pre-sowing treatments on growth and yield.

Effect of different presowing treatment PEG₆₀₀₀ 0.05%, and GA₃@0.05% on different morphological character

The present investigation was undertaken to assess the influence of various plant hormone pre-sowing treatments on phenotypic growth parameters and yield attributes in chickpea. The experiment encompassed a comprehensive evaluation of growth dynamics at different developmental stages, phenological events, yield components, and indices of resource partitioning, such as the harvest index. The results obtained provide valuable insights into how seed fortification interventions, when integrated with varietal characteristics, can contribute significantly to improving crop performance.

Among the GA₃-treated genotypes, DNA 334 + GA₃@0.05% recorded the highest plant height (19.33 cm) at 30 DAS, followed by Avrodhi + GA₃@0.05% (20.13 cm) and Pusa 362 + GA₃@0.05% (18.93 cm). Whereas PEG-treated genotypes showed a modest increase in early height. Himmat + PEG recorded 20.60 cm, the highest among PEG-treated entries, followed by Local + PEG₆₀₀₀@0.05% (18.60 cm) and Radhey + PEG (18.13 cm). These results suggest that PEG may help maintain early growth even under osmotic stress. Overall, GA₃-treated DNA 334 and Avrodhi, along with PEG-treated Himmat, showed relatively better performance in early plant height compared to other treated entries. For the GA₃-treated genotypes, DNA 334 + GA₃@0.05% recorded 60 DAS plant height the maximum height (23.53 cm), followed by Avrodhi + GA₃@0.05% (24.40 cm) and Pusa 362 + GA₃@0.05% (23.40 cm). For the PEG-treated genotypes, Himmat + PEG₆₀₀₀@0.05% recorded 24.60 cm, the tallest among PEG treatments, followed by Local + PEG₆₀₀₀@0.05% (22.80 cm) and Radhey + PEG₆₀₀₀@0.05% (21.80 cm). These results demonstrate that PEG treatment helped maintain vegetative

growth under induced stress conditions. Overall, PEG-treated Himmat and GA₃-treated Avrodhi showed better performance in terms of plant height at 60 DAS. The comparison also reveals that both treatments contributed to maintaining mid-stage plant height within an acceptable range. And the GA₃@0.05% treated genotypes, Pusa 362 + GA₃@0.05% recorded the highest plant height (60.40 cm), followed by Avrodhi + GA₃@0.05% (59.70 cm) and DNA 334 + GA₃@0.05% (59.47 cm). These values were noticeably higher than their respective controls, indicating that GA₃ application enhanced overall plant elongation up to the late growth stage. For the PEG-treated genotypes, Himmat + PEG showed the maximum height (55.81 cm), followed closely by Radhey + PEG₆₀₀₀@0.05% (56.07 cm) and Local + PEG₆₀₀₀@0.05% (55.23 cm). While PEG₆₀₀₀@0.05% -treated entries showed slightly lower heights than GA₃@0.05%-treated ones, they still performed better than untreated controls for some genotypes. For the GA₃-treated genotypes, Pusa 362 + GA₃@0.05% and Radhey + GA₃@0.05% recorded earlier flowering at 76.33 days, while DNA 334 + GA₃@0.05% flowered at 77.67 days and Avrodhi + GA₃@0.05% at 79.33 days. The treatment led to a marginal reduction in flowering days compared to their untreated counterparts, suggesting that GA₃ can hasten reproductive initiation. In the case of PEG₆₀₀₀@0.05% -treated genotypes, Local + PEG₆₀₀₀@0.05% showed the earliest flowering overall at 75.33 days, followed by Himmat + PEG₆₀₀₀@0.05% (76.67 days) and Radhey + PEG₆₀₀₀@0.05% (77.33 days). This indicates that PEG, under stress simulation, might induce early flowering as a stress escape mechanism. Effectively influenced the timing of flowering. With the GA₃-treated genotypes, the maximum number of pods per plant was recorded in Avrodhi + GA₃ (65.33 pods), followed by Pusa 362 + GA₃@0.05% (63.93 pods) and DNA 334 + GA₃@0.05% (62.30 pods). PEG₆₀₀₀@0.05% treatment, the number of pods per plant also improved. Himmat + PEG₆₀₀₀@0.05% showed 56.57 pods, Radhey + PEG₆₀₀₀@0.05% had 55.47 pods, and Local + PEG₆₀₀₀@0.05% recorded 44.50 pods, showing a noticeable increase over the untreated Local genotype (41.97 pods). This suggests that PEG₆₀₀₀@0.05% treatment may help sustain pod development under simulated drought stress. And the GA₃@0.05%-treated genotypes, the highest number of branches per plant was observed in Avrodhi + GA₃,

which recorded 6.03 branches, followed by DNA 334 + GA₃@0.05% (4.67) and Pusa 362 + GA₃@0.05% (5.13). These values were generally higher than their untreated counterparts, indicating that GA₃ application promoted enhanced branching. In case of PEG₆₀₀₀@0.05%-treated genotypes, Local + PEG₆₀₀₀@0.05% showed the maximum number of branches (6.07), followed by Himmat + PEG₆₀₀₀@0.05% (6.03) and Radhey + PEG₆₀₀₀@0.05% (5.97). And the GA₃-treated genotypes, the earliest maturity was observed in DNA 334 + GA₃ @0.05% (121.67 days), followed by Avrodhi + GA₃ @0.05% (122.00 days) and Pusa 362 + GA₃ @0.05% (122.33 days). These genotypes matured 7 to 8 days earlier than their untreated controls. In contrast, PEG₆₀₀₀ @0.05%-treated genotypes had relatively longer durations. Radhey + PEG₆₀₀₀ @0.05% and Local + PEG₆₀₀₀ @0.05% matured at 127.33 days, while Himmat + PEG₆₀₀₀ @0.05% and Local + PEG₆₀₀₀ @0.05% took 127.67 days. Although slightly delayed compared to GA₃-treated genotypes, PEG-treated plants still matured in synchrony with their controls, indicating PEG's stabilizing influence under stress conditions. With the GA₃-treated genotypes, Avrodhi + GA₃@0.05% recorded the highest seed yield per plot (1.48 kg), followed closely by Pusa 362 + GA₃@0.05% (1.48 kg) and DNA 334 + GA₃@0.05% (1.26 kg). These yields were substantially higher than their untreated counterparts. In the case of PEG₆₀₀₀ @0.05% -treated genotypes, Local + PEG₆₀₀₀ @0.05% recorded a yield of 1.31 kg per plot, followed by Radhey + PEG₆₀₀₀ @0.05% (1.11 kg) and Himmat + PEG₆₀₀₀ @0.05% (1.09 kg). These values indicated a moderate improvement in yield under stress-simulated conditions, especially in genotypes like Local that otherwise had lower control yields. With the GA₃@0.05%-treated genotypes, Pusa 362 + GA₃ @0.05% recorded the highest biological yield (1.98 kg), followed closely by Avrodhi + GA₃ @0.05% (1.94 kg) and DNA 334 + GA₃ @0.05% (1.86 kg). In case of PEG₆₀₀₀ @0.05%-treated genotypes, the highest biological yield was observed in Himmat + PEG₆₀₀₀ @0.05% (1.81 kg), followed by Local + PEG₆₀₀₀ @0.05% (1.74 kg) and Radhey + PEG₆₀₀₀ @0.05% (1.67 kg). Although lower than GA₃@0.05%-treated genotypes. And the GA₃-treated genotypes, the highest 100 seed weight was recorded in Pusa 362 + GA₃ @0.05% (27.97 g), followed by DNA 334 + GA₃ @0.05% (25.23 g) and Avrodhi + GA₃ @0.05% (23.40 g). In the case of PEG₆₀₀₀ @0.05%-treated genotypes, the highest 100 seed weight was noted in Local + PEG₆₀₀₀ @0.05% (26.17 g), followed by Himmat + PEG₆₀₀₀ @0.05% (22.00 g) and Radhey + PEG₆₀₀₀ @0.05% (20.23 g). These values, while slightly lower than GA₃-treated plants, still indicated a positive impact of PEG treatment on seed size. And the GA₃-treated genotypes, Pusa 362 + GA₃@0.05% recorded the highest harvest index (74.86%), followed closely by Avrodhi + GA₃@0.05%

(67.72%) and DNA 334 + GA₃@0.05%(67.38%). In the case of PEG-treated genotypes, Local + PEG₆₀₀₀ @0.05% showed the highest harvest index (75.25%), followed by Radhey + PEG₆₀₀₀ @0.05% (67.05%) and Himmat + PEG₆₀₀₀ @0.05% (60.47%). The improvement in HI under PEG treatment suggests its potential role in enhancing resource use efficiency under stress. Comparatively, both GA₃@0.05% and PEG₆₀₀₀ @0.05% treatments were effective, though PEG-treated Local genotype achieved the maximum HI, indicating that some genotypes respond particularly well to stress-induced treatments. With the GA₃-treated genotypes, Avrodhi + GA₃ @0.05% recorded the highest seed yield per plant (15.97 g), followed by Pusa 362 + GA₃ @0.05% (14.97 g) and DNA 334 + GA₃ @0.05% (14.80 g). In the case of PEG₆₀₀₀ @0.05%-treated genotypes, Radhey + PEG₆₀₀₀ @0.05% showed a seed yield per plant of 10.90 g, followed closely by Himmat + PEG₆₀₀₀ @0.05% (10.47 g) and Local + PEG₆₀₀₀ @0.05% (9.67 g). Similar finding is recorded by Hedden *et al.* 2015, Kumar *et al.* 2018, Koskosidis *et al.* 2020, Rafique *et al.* 2021, Ahmad *et al.* 2021, Lei *et al.* 2021, Komal *et al.* 2021, Indira *et al.* 2025 [2, 18, 19, 21, 21, 26, 27, 34].

Conclusion

The study revealed significant genetic and treatment-induced variability among chickpea genotypes and their respective PEG₆₀₀₀ and GA₃ treatments. GA₃ @0.05% proved effective in improving yield attributes, especially in genotypes like Avrodhi, DNA334, and Pusa 362, enhancing seed yield per plant, 100-seed weight, and harvest index. While PEG 6000 also enhanced certain vegetative traits like the number of branches, GA₃ was more effective in enhancing reproductive and yield traits. Thus, GA₃ priming can be recommended as a potential treatment to improve chickpea productivity under standard growth condition.

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Conflict of interest statement

The authors declare that they have no conflicts of interest to disclose. This research was carried out independently without any financial support or external funding.

The authors collectively contributed to the conception and design of this study. They were involved in data collection, analysis, and interpretation. The manuscript was jointly prepared, critically reviewed, and approved for final submission. All authors take full responsibility for the content and recommend it for publication in this journal.

Table 4.1: Analysis of Variance of different twelve characters of chickpea

Characters	Mean sum of squares		
	Replications	Treatment	Error
	(d.f=2)	(d.f=12)	(d.f=24)
DAS to 50% Flowering	1.36	8.14	1.45
Plant height 30 DAS	14.14	70.59	4.44
Plant height 60 DAS	11.42	77.75	3.89
Plant height 90 DAS	1.76	18.75	3.78
No. of pod / plant	3.50	155.15	4.41
No. of branches / plant	0.01	1.79	0.06

DAS to maturity	2.03	27.91	0.76
Seed yield / plot (kg)	0.01	0.12	0.00
Biological yield (kg)	0.03	0.15	0.01
100 Seed weight (g)	0.02	19.21	0.03
Harvest index (%)	11.95	117.80	38.25
Seed yield / plant (g)	0.11	15.27	0.79

Table 4.2: Analysis of mean performance of twelve different treated and untreated genotypes

Genotype	DAS to 50 % Flowering	Plant height 30 DAS	Plant height 60 DAS	Plant height 90 DAS	No. of pod plant	No. of branches per plant
PUSA 362	77.33	31.13	35.93	53.03	57.63	4.03
DNA334	77.00	31.73	36.73	53.77	58.70	3.97
AVRODHI	80.33	26.60	30.40	54.07	56.40	4.57
HIMMAT	79.67	21.33	26.13	55.13	61.37	4.60
RADHEY	76.33	19.07	23.27	55.73	52.50	5.07
LOCAL	80.00	20.47	24.67	53.83	41.97	5.13
PUSA362+GA ₃ @0.05%	76.33	18.93	23.40	60.40	63.93	5.13
DNA334+GA ₃ @0.05%	77.67	19.33	23.53	59.47	62.30	4.67
AVRODHI+GA ₃ @0.05%	79.33	20.13	24.40	59.70	65.33	6.03
HIMMAT+PEG ₆₀₀₀ @0.05%	76.67	20.60	24.60	55.81	56.57	6.03
RADHEY+PEG ₆₀₀₀ @0.05%	77.33	18.13	21.80	56.07	55.47	5.97
LOCAL+PEG ₆₀₀₀ @0.05%	75.33	18.60	22.80	55.23	44.50	6.07
Mean	77.78	22.17	26.47	56.02	56.39	5.11
SE	0.70	1.22	1.14	1.12	1.21	0.15
CD5%	2.04	3.57	3.34	3.29	3.55	0.43
CV	1.55	9.51	7.45	3.47	3.72	4.97
Max	80.33	31.73	36.73	60.4	65.33	6.07
Min	75.33	18.13	21.8	53.03	41.97	3.97

Table 4.3: Analysis of mean performance of different twelve genotypes of chickpea

Genotype	DAS to maturity	Seed yield per plot (kg)	Biological yield (kg)	100 Seed weight (g)	Harvest index (%)	Seed yield per plant (g)
PUSA 362	130.00	0.95	1.58	22.53	60.40	11.03
DNA334	129.67	1.08	1.82	24.07	59.27	12.57
AVRODHI	128.67	1.50	2.02	21.20	74.27	11.50
HIMMAT	129.67	1.13	1.62	25.37	70.79	12.87
RADHEY	127.67	0.81	1.24	26.87	65.53	9.83
LOCAL	127.33	1.20	1.55	20.80	77.42	9.23
PUSA362+GA ₃ @0.05%	122.33	1.48	1.98	27.97	74.86	14.97
DNA334+GA ₃ @0.05%	121.67	1.26	1.86	25.23	67.38	14.80
AVRODHI+GA ₃ @0.05%	122.00	1.30	1.94	23.40	67.72	15.97
HIMMAT+PEG ₆₀₀₀ @0.05%	127.67	1.09	1.81	22.00	60.47	10.47
RADHEY+PEG ₆₀₀₀ @0.05%	127.33	1.11	1.67	20.23	67.05	10.90
LOCAL+PEG ₆₀₀₀ @0.05%	127.67	1.31	1.74	26.17	75.25	9.67
Mean	126.81	1.19	1.74	23.82	68.37	11.98
SE	0.50	0.03	0.07	0.10	3.57	0.51
CD5%	1.47	0.08	0.19	0.28	10.47	1.51
CV	0.69	4.01	6.57	0.70	9.05	7.44
Max	130	1.5	2.02	27.97	77.42	15.97
Min	121.67	0.81	1.24	20.23	59.27	9.23

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