International Journal of Advanced Biochemistry Research 2025; SP-9(8): 761-767

International Journal of Advanced Biochemistry Research

ISSN Print: 2617-4693
ISSN Online: 2617-4707
NAAS Rating (2025): 5.29
IJABR 2025; SP-9(8): 761-767
www.biochemjournal.com
Received: 01-06-2025
Accepted: 02-07-2025

Jashwant Patel
M.Sc. Student, Faculty of Agriculture, Prof. Rajendra Singh (Rajju Bhaiya) University, Prayagraj, Uttar Pradesh, India

Sachchida Nand Mishra
Faculty of Agriculture, Prof. Rajendra Singh (Rajju Bhaiya) University, Prayagraj, Uttar Pradesh, India

Rahul Kumar Patel
M.Sc. Student, Faculty of Agriculture, Prof. Rajendra Singh (Rajju Bhaiya) University, Prayagraj, Uttar Pradesh, India

Shubham
M.Sc. Student, Faculty of Agriculture, Prof. Rajendra Singh (Rajju Bhaiya) University, Prayagraj, Uttar Pradesh, India

Sonoo Singh
M.Sc. Student, Department of Genetics and Plant Breeding, Mahatma Gandhi Kashi Vidyapith, Varanasi, Uttar Pradesh, India

Corresponding Author:
Sachchida Nand Mishra
Faculty of Agriculture, Prof. Rajendra Singh (Rajju Bhaiya) University, Prayagraj, Uttar Pradesh, India

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

Jashwant Patel, Sachchida Nand Mishra, Rahul Kumar Patel, Shubham and Sonoo Singh

DOI: https://www.doi.org/10.33545/26174693.2025.v9.i8Sl.5250

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 GA_3 0.5% and PEG $_{6000}$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+PEG_{6000} @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+GA_3 @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+GA_3 @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+GA_3 @0.05% (15.97 g).

Keywords: Chickpea, genotype, environmental, fortification, GA_3, PEG_{6000}

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) [11].

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 × environment (G×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 PEG_{6000} and GA_3 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+GA_3@0.05%, (T_7)
- DNA334+GA_3 @0.05%, (T_8)
- AVRODHI+GA_3@0.05% (T_9)
- HIMMAT+PEG_{6000}@0.05%(T_{10})
- RADHEY+PEG_{6000}@0.05%(T_{11})
- LOCAL+ PEG_{6000}@0.05%(T_{12})


Fig 1: Field prepration and seed sowing. **Fig 2:** With adivsor 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 PEG_{600}.005%, and GA_3@0.05% on different morphological character

The present investigation was undertaken to assess the influence of various plant haromonl 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 GA_3-treated genotypes, DNA 334 + GA_3@0.05% recorded the highest plant height (19.33 cm) at 30 DAS, followed by Avrodhi + GA_3@0.05% (20.13 cm) and Pusa 362 + GA_3@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 + PEG_{6000}@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, GA_3-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 GA_3-treated genotypes, DNA 334 + GA_3@0.05% recorded 60 DAS plant height the maximum height (23.53 cm), followed by Avrodhi + GA_3 @0.05% (24.40 cm) and Pusa 362 + GA_3@0.05% (23.40 cm). For the PEG-treated genotypes, Himmat + PEG_{6000}@0.05% recorded 24.60 cm, the tallest among PEG treatments, followed by Local + PEG_{6000}@0.05% (22.80 cm) and Radhey + PEG_{6000}@0.05% (21.80 cm). These results demonstrate that PEG treatment helped maintain vegetative growth under induced stress conditions. Overall, PEG-treated Himmat and GA_3-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 GA_3-@0.05% treated genotypes, Pusa 362 + GA_3@0.05% recorded the highest plant height (60.40 cm), followed by Avrodhi + GA_3@0.05% (59.70 cm) and DNA 334 + GA_3@0.05% (59.47 cm). These values were noticeably higher than their respective controls, indicating that GA_3 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 + PEG_{6000} @0.05% (56.07 cm) and Local + PEG_{6000} @0.05% (55.23 cm). While PEG_{6000} @0.05% -treated entries showed slightly lower heights than GA_3 @0.05%-treated ones, they still performed better than untreated controls for some genotypes. For the GA_3-treated genotypes, Pusa 362 + GA_3@0.05% and Radhey + GA_3@0.05%recorded earlier flowering at 76.33 days, while DNA 334 + GA_3@0.05%flowered at 77.67 days and Avrodhi + GA_3@0.05% at 79.33 days. The treatment led to a marginal reduction in flowering days compared to their untreated counterparts, suggesting that GA_3 can hasten reproductive initiation. In the case of PEG_{60000} @0.05% -treated genotypes, Local + PEG_{60000} @0.05% showed the earliest flowering overall at 75.33 days, followed by Himmat + PEG_{60000} @0.05% (76.67 days) and Radhey + PEG_{60000} @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 GA_3-treated genotypes, the maximum number of pods per plant was recorded in Avrodhi + GA_3 (65.33 pods), followed by Pusa 362 + GA_3@0.05% (63.93 pods) and DNA 334 + GA_3@0.05% (62.30 pods). PEG_{6000} @0.05% treatment, the number of pods per plant also improved. Himmat + PEG_{6000} @0.05% showed56.57 pods, Radhey + PEG_{6000} @0.05% had 55.47 pods, and Local + PEG_{6000} @0.05% recorded 44.50 pods, showing a noticeable increase over the untreated Local genotype (41.97 pods). This suggests that PEG_{6000} @0.05% treatment may help sustain pod development under simulated drought stress. And the GA_3@0.05%-treated genotypes, the highest number of branches per plant was observed in Avrodhi + GA_3, which recorded 6.03 branches, followed by DNA 334 + GA_3@0.05%- (4.67) and Pusa 362 + GA_3@0.05% (5.13). These values were generally higher than their untreated counterparts, indicating that GA_3 application promoted enhanced branching. In case of PEG_{6000}@0.05%treated genotypes, Local + PEG_{6000}@0.05% showed the maximum number of branches (6.07), followed by Himmat + PEG_{6000}@0.05% (6.03) and Radhey + PEG_{6000}@0.05% (5.97).And the GA_3-treated genotypes, the earliest maturity was observed in DNA 334 + GA_3 @0.05% (121.67 days), followed by Avrodhi + GA_3 @0.05% (122.00 days) and Pusa 362 + GA_3 @0.05% (122.33 days). These genotypes matured 7 to 8 days earlier than their untreated controls. In contrast, PEG $_{6000}$ @0.05%-treated genotypes had relatively longer durations. Radhey + PEG $_{6000}$ @0.05% and Local + PEG $_{6000}$ @0.05% matured at 127.33 days, while Himmat + PEG $_{6000}$ @0.05% and Local + PEG $_{6000}$ @0.05% took 127.67 days. Although slightly delayed compared to GA_3-treated genotypes, PEG-treated plants still matured in synchrony with their controls, indicating PEG's stabilizing influence under stress conditions. With the GA_3-treated genotypes, Avrodhi + GA_3@0.05% recorded the highest seed yield per plot (1.48 kg), followed closely by Pusa 362 + GA_3@0.05% (1.48 kg) and DNA 334 + GA_3@0.05% (1.26 kg). These yields were substantially higher than their untreated counterparts. In the case of PEG $_{6000}$ @0.05% -treated genotypes, Local + PEG $_{6000}$ @0.05% recorded a yield of 1.31 kg per plot, followed by Radhey + PEG $_{6000}$ @0.05% (1.11 kg) and Himmat + PEG $_{6000}$ @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 GA_3@0.05%-treated genotypes, Pusa 362 + GA_3 @0.05% recorded the highest biological yield (1.98 kg), followed closely by Avrodhi + GA_3 @0.05% (1.94 kg) and DNA 334 + GA_3 @0.05% (1.86 kg). In case of PEG $_{6000}$ @0.05%-treated genotypes, the highest biological yield was observed in Himmat + PEG $_{6000}$ @0.05% (1.81 kg), followed by Local + PEG $_{6000}$ @0.05% (1.74 kg) and Radhey + PEG $_{6000}$ @0.05% (1.67 kg). Although lower than GA_3@0.05%-treated genotypes. And the GA_3-treated genotypes, the highest 100 seed weight was recorded in Pusa 362 + GA_3 @0.05% (27.97 g), followed by DNA 334 + GA_3 @0.05% (25.23 g) and Avrodhi + GA_3 @0.05% (23.40 g). In the case of PEG $_{6000}$ @0.05%-treated genotypes, the highest 100 seed weight was noted in Local + PEG $_{6000}$ @0.05% (26.17 g), followed by Himmat + PEG $_{6000}$ @0.05% (22.00 g) and Radhey + PEG $_{6000}$ @0.05% (20.23 g). These values, while slightly lower than GA_3-treated plants, still indicated a positive impact of PEG treatment on seed size. And the GA_3-treated genotypes, Pusa 362 + GA_3@0.05% recorded the highest harvest index (74.86%), followed closely by Avrodhi + GA_3@0.05% (67.72%) and DNA 334 + GA_3@0.05%(67.38%). In the case of PEG-treated genotypes, Local + PEG $_{6000}$ @0.05% showed the highest harvest index (75.25%), followed by Radhey + PEG $_{6000}$ @0.05% (67.05%) and Himmat + PEG $_{6000}$ @0.05% (60.47%). The improvement in HI under PEG treatment suggests its potential role in enhancing resource use efficiency under stress. Comparatively, both GA_3@0.05% and PEG $_{6000}$ @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 GA_3-treated genotypes, Avrodhi + GA_3 @0.05% recorded the highest seed yield per plant (15.97 g), followed by Pusa 362 + GA_3 @0.05% (14.97 g) and DNA 334 + GA_3 @0.05% (14.80 g). In the case of PEG_{6000} @0.05%-treated genotypes, Radhey + PEG_{6000} @0.05% showed a seed yield per plant of 10.90 g, followed closely by Himmat + PEG 6000 @0.05% (10.47 g) and Local + PEG_{6000} @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 PEG_{6000} and GA_3 treatments. GA_3 @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, GA_3 was more effective in enhancing reproductive and yield traits. Thus, GA_3 priming can be recommended as a potential treatment to improve chickpea productivity under standard growth condition.

Acknowledgment

The authors and Prof. Rajendra Singh (Rajju Bhaiya) University, Prayagraj, UP, India, are gratefully acknowledged for providing all necessary facilities and resources.

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 (d.f=2)	Treatment (d.f=12)	Error (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

References

1. Agarwal G, Jhanwar S. Comparative analysis of kabuli chickpea transcriptome with desi and wild chickpea provides a rich resource for development of functional markers. PLoS ONE. 2012;7(12):e52443.
2. Ahmad P, Raja V, Ashraf M, Wijaya L, Bajguz A, Alyemeni MN, *et al.* Jasmonic acid (JA) and gibberellic acid (GA_3) mitigated Cd-toxicity in chickpea plants through restricted Cd uptake and oxidative-stress management. Sci Rep. 2021;11:19768.
3. Ahmed HGM, Sajid M, Muhammad Z. Screening of chickpea genotypes for drought tolerance using polyethylene glycol. J Anim Plant Sci. 2014;24(5):1412-1419.
4. Anjum SA, Wang LC, Farooq M, Hussain M, Xue LL, Zou CM. Brassinolide application improves the drought tolerance in maize through modulation of enzymatic antioxidants and leaf gas exchange. J Agron Crop Sci. 2011;197(3):177-185.
5. Anwar MR, Liu DL, Macadam I, Kelly G. Climate change impacts on phenology and yield of chickpea in south-eastern Australia. Agric For Meteorol. 2022;323:109035.
6. Bashir F, Khan A, Ahmad R, Ali M. Gibberellic acid-mediated regulation of growth and yield in chickpea (*Cicer arietinum* L.) under normal and stress conditions. Legume Res. 2021;44(9):1045-1051.
7. Chauhan V, Hirpara DS, Bheda MK, Sutaria GS. Response of chickpea (*Cicer arietinum* L.) to plant

growth regulators. J Pharmacogn Phytochem. 2018;7(6):669-672.
8. Craufurd PQ, Peacock JM. Effect of heat and drought stress on sorghum (Sorghum bicolor). II. Grain yield. Exp Agric. 1993;29(1):77-86.
9. Devasirvatham V, Gaur PM, Raju TN, Trethowan RM, Tan DKY. Field response of chickpea (*Cicer arietinum* L.) to high temperature. Field Crops Res. 2012;142:9-18.
10. Diapari M, Sindhu A, Bett K, Deokar A, Warkentin TD, Tar'an B. Genetic diversity and association mapping of iron and zinc concentrations in chickpea (*Cicer arietinum* L.). Genome. 2014;57(8):459-468.
11. FAOSTAT. FAOSTAT database. Rome: Food and Agriculture Organization of the United Nations; 2011.
12. FAOSTAT. FAOSTAT statistical database. Rome: Food and Agriculture Organization of the United Nations; 2023.
13. Farooq M, Wahid A, Siddique KHM. Seed priming improves seedling establishment, growth, and drought tolerance in crops. Plants. 2022;11(3):435.
14. Farooq M, Wahid A, Kobayashi N, Fujita D, Basra SMA. Plant drought stress: effects, mechanisms and management. Agron Sustain Dev. 2009;29:185-212.
15. Farooq M, Wahid A, Kobayashi N, Fujita D, Basra SMA. Plant drought stress: effects, mechanisms and management. Agron Sustain Dev. 2012;29:185-212.
16. Guo T. Genetic improvement of chickpeas: Traits, targets, and technology. Legume Genomics Genet. 2024;15. doi:10.5376/lgg.2024.15.0001.
17. Hamim Reja M, Sikder S, Hasan MA, Pramanik SK. The combined effects of gibberellic acid and Rhizobium on growth, yield and nutritional status in chickpea (*Cicer arietinum* L.). Agronomy. 2020;11(1):105.
18. Hedden P, Sponsel V. A century of gibberellin research. J Plant Growth Regul. 2015;34(4):740-60.
19. Indira MN, Angeline AR, Ankit K, Vaishnavi S. Impact of osmotic stress on seed germination and seedling growth in chickpea (*Cicer arietinum* L.). Agric Sci Dig. 2025;1-5.
20. Kaushal N, Awasthi R, Gupta K, Gaur P, Siddique KHM, Nayyar H. Heat-stress-induced reproductive failures in chickpea (*Cicer arietinum* L.) are associated with impaired sucrose metabolism in leaves and anthers. Funct Plant Biol. 2013;40(12):1334-1349.
21. Khan AM, Ali Z, Mohsin AU, *et al.* Genotype × environment interactions analysis for chickpea grain yield and related traits by a mixed model approach. Discov Agric. 2024;2:90.
22. Khan MN, Zhang J, Luo T, Liu J, Rizwan M. Seed priming with plant growth regulators and its implications for improving drought tolerance in crop plants. Plant Growth Regul. 2020;90:241-256.
23. Komal Meramanbhai BER. Effect of seed priming on chickpea (*Cicer arietinum* L.) [doctoral dissertation]. Sardarkrushinagar: Sardarkrushinagar Dantiwada Agricultural University; 2021.
24. Koskosidis A, Khah E, Mavromatis A, Pavli O, Vlachostergios DN. Effect of PEG-induced drought stress on germination of ten chickpea (*Cicer arietinum* L.) genotypes. Not Bot Horti Agrobo. 2020;48(1):294-304.
25. Kumar R, Rai PK. Effect of different priming methods and durations for Kabuli chickpea (*Cicer arietinum* L.) seeds. Int J Curr Microbiol Appl Sci. 2020;9(2):532-9.
26. Kumar R, Sharma SK, Singh R, Sharma SK. Effect of plant growth regulators on growth and yield of blackgram (*Vigna mungo* L.). J Pharmacogn Phytochem. 2018;7(1):2781-4.
27. Lei C, Bagavathiannan M, Wang H, Sharpe SM, Meng W, Yu J. Osmopriming with polyethylene glycol (PEG) for abiotic stress tolerance in germinating crop seeds: a review. Agronomy. 2021;11(11):2194.
28. Maphosa L, Richards MF, Norton SL, Nguyen GN. Breeding for abiotic stress adaptation in chickpea (*Cicer arietinum* L.): A comprehensive review. Crop Breed Genet Genom. 2020;4(3).
29. Mut Z, Akay H, Sezer I. Effects of different doses of gibberellic acid on seed germination, seedling growth and flowering time in wheat (Triticum aestivum L.). J Food Agric Environ. 2010;8(2):220-222.
30. Hura T, Hura K, Weidner S. Seed priming: A feasible strategy to enhance drought tolerance in crops. Int J Mol Sci. 2020;21(21):8258.
31. Ni J, Gao C, Chen MS, Pan BZ, Ye K, Xu ZF. Gibberellin promotes shoot branching in the perennial woody plant Jatropha curcas. Plant Cell Physiol. 2015;56(8):1655-1666.
32. Panse VG, Sukhatme PV. Statistical methods for agricultural workers. 2nd ed. New Delhi: Indian Council of Agricultural Research; 1967.
33. Purushothaman R, Krishnamurthy L, Upadhyaya HD, Vadez V, Varshney RK. Genotypic variation in soil water use and root distribution and their implications for drought tolerance in chickpea. Funct Plant Biol. 2017;44(3):235-252.
34. Rafique M, Naveed M, Mustafa A, Akhtar S, Munawar M, Kaukab S, *et al.* The combined effects of gibberellic acid and Rhizobium on growth, yield and nutritional status in chickpea (*Cicer arietinum* L.). Agronomy. 2021;11(1):105.
35. Rani A, Devi P, Jha UC, Sharma KD, Siddique KHM, Nayyar H. Developing climate-resilient chickpea involving physiological and molecular approaches with a focus on temperature and drought stresses. Front Plant Sci. 2020;10:1759.
36. Reja MS, Sikder S, Hasan MA, Pramanik SK. Effect of gibberellic acid (GA_3) on morpho-physiological traits and yield performance of chickpea (*Cicer arietinum* L.). IOSR J Agric Vet Sci. 2020;13(7):20-28.
37. Kumar R, Rai PK. Effect of different priming methods and durations for Kabuli chickpea (*Cicer arietinum* L.). Int J Curr Microbiol Appl Sci. 2020;9(2):532-539.
38. Kumar R, Rai PK. Effect of different priming methods and durations for Kabuli chickpea (*Cicer arietinum* L.). Int J Curr Microbiol Appl Sci. 2020;9(2):3162-3171.
39. Sarvjeet SC, Gupta JP, Singh A. Determination of best combination of bio-fortification and hydro-priming for yield and its quality parameters in chickpea (*Cicer arietinum* L.). J Pharmacogn Phytochem. 2017;6(3):835-840.
40. Segev A, Badani H, Galili S, Hovav R, Kapulnik Y, Shomer I, *et al.* Total phenolic content and antioxidant activity of chickpea (*Cicer arietinum* L.) as affected by soaking and cooking. J Food Sci. 2010;75(2):H115-H119.

41. Shariatmadari H, Ghassemi-Golezani K, Zomorodian K. [Title of study] (covers GA_3 effects on seed germination and seedling growth under PEG-induced stress in chickpea). [Journal]. 2022.
42. Singh M, Yadav SS, Kumar A. Effect of PEG-6000 induced osmotic stress on germination and seedling growth in chickpea (*Cicer arietinum* L.) genotypes. Agric Sci Dig. 2019;39(1):37-41.
43. Singh R, Kumar S, Sharma N. Screening of chickpea genotypes for drought tolerance using morpho-physiological traits under PEG-induced osmotic stress. Legume Res. 2021;44(5):543-550.
44. Tripathi S, Singh RK, Parida SK, Chaturvedi SK, Gaur PM. Biofortification of chickpea. In: Kumar S, Dikshit HK, Mishra GP, Singh A, editors. Biofortification of staple crops. Singapore: Springer; 2022. p. 351-372.
45. Upadhyaya HD, Dronavalli N, Gowda CLL, Singh S. Identification and evaluation of chickpea germplasm for genetic biofortification of iron and zinc. J SAT Agric Res. 2016;14:1-7.
46. Vadez V, Krishnamurthy L, Thudi M, Anuradha C, Colmer TD, Turner NC, *et al.* Assessment of ICCV 2 × JG 62 chickpea progenies for salinity tolerance in relation to reproductive success and water use efficiency. Plant Soil. 2012;365(1-2):267-279.
47. Wahid A, Gelani S, Ashraf M, Foolad MR. Heat tolerance in plants: An overview. Environ Exp Bot. 2007;61(3):199-223.
48. Wozny D, Petřivalský M, Kurešová G. Gibberellins accelerate plant development and flowering in barley through regulation of floral induction pathways. Front Plant Sci. 2021;12:694424.
49. Yadav A, Garg VK. Influence of vermi-fortification on chickpea (*Cicer arietinum* L.) growth and photosynthetic pigments. Int J Recycl Org Waste Agricult. 2015;4:299-305.
50. Yang R, Xue L, Zhang L, Wang X, Qi X, Jiang J, *et al.* Bioactive components and health benefits of chickpeas. Crit Rev Food Sci Nutr. 2020;60(11):1886-1905.