Plant Archives Vol. 26, Supplement 2, 2026 pp.3229-3238 e-ISSN:2581-6063 (online), ISSN:0972-5210

Plant Archives

Journal homepage: http://www.plantarchives.org
DOI Url : https://doi.org/10.51470/PLANTARCHIVES.2026.v26.supplement-2.411

OPTIMIZATION OF SEED RATE FOR ENHANCING SEED YIELD AND QUALITY IN SMALL SEEDED CHICKPEA (*Cicer arietinum* L.)

Bharath B.K.[1], Basavaraja B.[2*], Anand, S.R.[3], Venkappa P.[1], Parashivamurthy[1], Siddaraju R.[1] and Radha B.N.[1]

[1]Department of Seed Science and Technology, CoA, UAS, GKVK, Bengaluru- 560 065, Karnataka, India
[2]AICRP on Seed (Crops), NSP, GKVK, Bengaluru- 560 065, Karnataka, India
[3]AICRP on Weed Management, UAS, GKVK, Bengaluru- 560 065, Karnataka, India
*Corresponding author E-Mail: basavaraja.sst@gmail.com
(Date of Receiving : 09-05-2026; Date of Revision : 03-07-2026; Date of Acceptance : 23-07-2026)

ABSTRACT

A field experiment was conducted during rabi 2024 at AICRP on Seed (Crops), NSP, GKVK, UAS, Bangalore to determine the optimum seed rate for maximizing seed yield and quality in chickpea. The experiment consisted of ten treatments with three replications, involving two varieties (Super Annigeri-1 and Phule Vikrant) and five different seed rates (75, 67.5, 60, 52.5 and 45 kg/ha) using factorial randomized complete block design. Among the two varieties, Super Annigeri-1 recorded the highest plant stand establishment (25.58/m 2), plant height at harvest (48.11 cm), number of effective nodules (17.90), number of branches per plant (2.9), number of pods per plant (52.2), seed yield (1837.5 kg/ha), seed recovery (89.41%), hundred seed weight (25.11 g), seed thickness (6.74 mm), seed germination (92.20 %), SV-I (3410), SV-II (6172), total dehydrogenase activity (0.94) and protein content (22.18 %) compared to Phule Vikrant (23.07/m 2, 45.15 cm, 16.78, 2.7, 48.3, 1704.8 kg/ha, 84.18%, 23.13 g, 6.43, 90.25%, 2763, 5950, 0.82 and 19.80% respectively. Among the different seed rates, T_1 (75 kg/ha) recorded highest seed yield parameters viz., pod yield (3009.7 kg/ha) and seed yield (1924.6 kg/ha) this was on par with T_2 (67.5 kg/ha) which recorded pod yield (2808.0 kg/ha) and seed yield (1704.8 kg/ha) whereas seed recovery was recorded maximum (92.87 %) in T_5 and minimum in T_1 (82.02 %). Higher values were observed in seed quality parameters with T_5 (45 kg/ha) viz., pure live seed (94.98%), hundred seed weight (26.01 g), seed thickness (6.82 mm), germination (93.25%), SV-I (3318), SV-II (6349), TDH activity at A480nm (0.95) and protein content (22.00%) and lower values for all these seed quality parameters were recorded with T_1 (75 kg/ha). Highest B:C ratio was recorded among interaction V_1T_2 (2.82) and V_2T_2 (2.45). The study revealed that, by considering all the seed yield and quality parameters into account, it can be concluded that seed rate T_2 (67.5 kg/ha) gives on par results with T_1 (75 kg/ha) along with improved seed quality. Hence the seed rate of these two chickpea varieties could be possibly reduced by 10 per cent.
Keywords **:** Chickpea, Optimum seed rate, Seed yield, Seed quality.

Introduction

Leguminous crops play a vital role in global agriculture and are ranked third among flowering plants in terms of species diversity. In India, legumes have been an integral part of traditional agriculture for centuries, forming a primary source of dietary protein, especially for low-income populations. These crops are not only essential for human nutrition due to their high protein content, but also contribute significantly to sustainable agriculture by enhancing soil fertility through biological nitrogen fixation. They can establish symbiotic associations with rhizobium bacteria in root nodules, which allows them to fix atmospheric nitrogen and consequently lowers the reliance on synthetic fertilizers.

Globally, pulses are cultivated on approximately 78 million hectares, with India alone contributing to nearly 34% of this area and accounting for around 24%

of global production. According to the Ministry of Agriculture and Farmer's Welfare (2023), India's pulse production reached about 26.96 million tonnes, grown over an area of 30.5 million hectares, with an average productivity of around 885 kg/ha (Government of India, 2023). In Karnataka, it is grown over an area of 8.22 lakh ha with a production of 5.59 lakh tonnes and productivity of 6.8 q/ha (Government of Karnataka, 2024).

Among pulse crops, chickpea (*Cicer arietinum* L.) is recognized as the most widely cultivated cool-season food legume, ranking after dry beans and dry peas. It has a deep-rooted history of cultivation in the Indian subcontinent, West Asia and North Africa. In recent decades, its cultivation has expanded to non-traditional areas such as North America and Australia due to its adaptability and rising global demand. Chickpea is a diploid species (2n = 2x = 16). It belongs to the genus *Cicer*, under the family Fabaceae (formerly Leguminosae) and the subfamily Papilionoideae.

Chickpea (*Cicer arietinum* L.) is a nutritionally valuable pulse crop that plays an important role in human diets, particularly in vegetarian populations. It is an annual crop that is typically grown in warm and dry climates. It is adapted to a wide range of soil types but thrives in well-drained soils with a pH range of 6.0 to 7.5. Chickpea is a relatively drought-tolerant crop and can be grown with minimal irrigation in areas with low rainfall. Chickpea also has potential as a climate-resilient crop that can help farmers adapt to the impacts of climate change. It is a rich source of plant-based protein, providing approximately 20–25% protein content, along with significant levels of complex carbohydrates (60–65%), dietary fiber and beneficial fats (5–6%) (Anon., 2023). Additionally, chickpeas supply a broad spectrum of essential micronutrients, including B vitamins, iron, phosphorus, magnesium and trace elements, making them a nutritionally dense food option (Bhuker *et al.*, 2023)

Globally, chickpeas are classified into two major cultivar groups: Desi and Kabuli, which represent two distinct genetic pools. Chickpea is the popular crop cultivated in *rabi* season to take best possible benefits of residual moisture and nutrients (Mohan Kumar and Nadagouda, 2020). Kabuli chickpeas exhibit a semi-spreading growth habit and generally lack anthocyanin pigmentation in both stem and flower tissues. In contrast, the Desi type is predominantly grown in South Asia, including India, Pakistan and Bangladesh, as well as in Ethiopia and parts of East Africa. Desi chickpeas are recognized for their smaller, angular seeds with rough surfaces, dark-coloured seed coats and pink to purple flowers. They often exhibit anthocyanin pigmentation on the stem and flowers and display either a semi-erect or semi-spreading growth habit. These morphological and physiological differences between the two types have significant implications for their adaptation to diverse agro-climatic zones and consumer preferences (Reddy *et al.*, 2016)

One of the main reasons of variation in yield of chickpea is improper population due to high seed rate. Both excessively low and overly high plant populations beyond a certain threshold often have a negative impact on crop yield. Small-seeded varieties of chickpea, due to their lower individual seed weight, allow for a greater number of seeds per kilogram, enabling the establishment of an ideal plant population even at reduced seed rates. When the seed rate is optimized for small-seeded varieties, it ensures a uniform and optimum plant stand by reducing intra-specific competition for essential resources such as nutrients, water and light. The number of plants per unit area affects plant size, yield attributes, and ultimately seed yield. In addition, proper plant spacing in the field is crucial to ensure adequate aeration and light penetration into the canopy, thereby optimizing the rate of photosynthesis. This balanced plant population facilitates better pod filling and physiological maturity, leading to well-developed seeds with uniform size and weight. Adequate spacing between plants reduces disease pressure and enhances aeration, thereby improving seed health and reducing the risk of seed-borne pathogens. Lower plant competition also allows for improved carbohydrate translocation and nutrient partitioning to developing seeds, resulting in higher seed vigour and improved seed thickness.

Overcrowding of seeds can lead to competition for resources such as water, nutrients, and sunlight, which can hinder germination and seedling growth. On the other hand, inadequate plant population can lead to reduced yield potential. Although a higher seed rate can lead to increased plant density, which can result in higher yields due to better use of available resources, but excessively high seed rates can lead to overcrowding, increased competition and reduced yields. If the seed rate is decreased without negatively impacting seedling vigour or seed yield, it would lead to a significant reduction in input costs by using a smaller amount of seed per unit area. The expense associated with chickpea seeds, which is a significant input cost, can be effectively minimized by utilizing the optimal seeding rate (Bhuker *et al.*, 2023).

Keeping all these aspects in view, the present investigation "Optimization of seed rate for enhancing seed yield and quality in small seeded chickpea (*Cicer arietinum* L.)" was undertaken with the following objectives.

1. To determine the optimum seed rate for maximizing seed yield
2. To investigate the effect of optimum seed rate on seed quality
3. To estimate the benefit- cost ratio of using optimal seed rates

Material and Methods

The experiment was conducted at All India Co-ordinated Research Project on Seed (Crops), Gandhi Krishi Vignana Kendra (GKVK), University of Agricultural Sciences (UAS), Bangalore. The centre is situated in the agro-climatic zone V: Eastern Dry Zone of Karnataka at 12°58' North latitude and 77°35' East longitude with an altitude of 924 m above mean sea level.

The experiment laid out in Factorial Randomized Complete Block Design with with two factors i.e., Factor 1 (two varieties), Factor 2 (five different seed rates) and three replications which include, V_1: Super Annigeri 1, V_2: Phule Vikrant, T_1: 75 kg/ha (Recommended seed rate), T_2: 67.5 kg/ha (10% less than recommended seed rate), T_3: 60 kg/ha (20% less than recommended seed rate), T_4: 52.5 kg/ha (30% less than recommended seed rate), T_5: 45 kg/ha (40% less than recommended seed rate). The recommended dose of fertilizer is 10:20:20 kg N: P_2O_5: K_2O ha^{-1} and FYM @ 7.5 t ha^{-1} common for all treatments.

Sowing was done on 25th November, 2024 by using UAS, Raichur released Super Annigeri 1 and MPKV, Rahuri released Phule Vikrant varieties. FYM was applied before 15 days of sowing to all the treatment plots at the rate of 7.5 tonnes ha^{-1}. Urea, single super phosphate and muriate of potash were used as a source of NPK. Thinning was performed at 15 days after sowing (DAS) by removing surplus seedlings from each hill, leaving only one healthy plant per hill. Earthing up at 40 DAS promoted vigorous growth and helped prevent lodging. For pest control, a foliar spray of Dimethoate at 2ml per litre of water was applied to control aphids and other sucking insects.

The crop had attained the maturity at 105 DAS. The border lines were harvested first and removed from the experimental area. Five randomly selected plants from each net plot were harvested separately for recording necessary biometric and yield observations. Subsequently, the pods from net plot area were harvested and sundried for about 4-5 days. After drying, threshing was carried out manually by beating the pods with a stick and seeds were cleaned manually. The seed weight from each net plot was then recorded individually after the completion of threshing.

The seed quality analysis was carried out with factorial completely randomized design at laboratory. The seed samples collected after harvest were evaluated for the seed germination and expressed as percentage (Anon., 2021). Seed vigour index was calculated using the formula of Abdul-Baki and Anderson (1973). The mean values of each treatment were calculated by averaging all replications. The data collected across various parameters were analyzed using Fisher's method of analysis of variance (ANOVA), following the procedure outlined by Snedecor and Cochran (1967). A significance level of P = 0.05 was applied for both the F-test and t-test. When the F-test indicated significant differences among treatment means, the corresponding critical difference (CD) was computed to facilitate comparison.

Results and Discussion

Efficacy of optimum seed rate on seed yield

The data in table 1 depicts the effect of optimum seed rate on plant growth parameters. Among the two varieties, Super Annigeri-1 recorded the maximum field emergence (80.75 %), highest plant stand establishment (25.58/m ^{2}), plant height at 30, 60 DAS and harvest (20.79, 35.49 and 48.11 cm), number of branches per plant (2.93), less days to 50% flowering (45.33) and days to maturity (102.73) compared to Phule Vikrant which recorded minimum field emergence (76.36 %), highest plant stand establishment (23.07/m ^{2}), plant height at 30, 60 DAS and harvest (18.96, 33.42 and 45.15 cm), number of branches per plant (2.76), more days to 50% flowering (48.91) and days to maturity (109.44).

Table 1 : Effect on plant growth parameters of chickpea due to optimization of seed rate

Treatments	Field emergence (%)	Plant stand establishment (per m^2)	Plant height (cm)			No. of branches per plant	Days to	
			30 days	60 days	Harvest		50% flowering	Maturity
Varieties (V)								
V_1–SA_1	80.75	25.58	20.79	35.49	48.11	2.93	45.33	102.73
V_2–Phule Vikrant	76.36	23.07	18.96	33.42	45.15	2.76	48.91	109.44
SEm±	**1.47**	**0.49**	**0.49**	**0.65**	**0.87**	**0.06**	**0.89**	**1.97**

CD (P=0.05)	**NS**	**1.45**	**1.45**	**1.93**	**2.57**	**0.17**	**2.66**	**5.85**
Different seed rates (T)								
T_1 -75kg/ha	81.57	29.08	22.21	37.79	51.49	2.38	49.55	109.05
T_2-67.5kg/ha	80.00	27.14	21.61	37.20	50.33	2.42	48.72	108.26
T_3 -60 kg/ha	78.46	24.44	19.12	34.00	46.18	2.71	46.52	105.49
T_4-52.5kg/ha	77.15	21.49	18.39	32.80	43.86	3.16	45.65	104.18
T_5 -45 kg/ha	75.61	19.46	18.03	30.47	41.29	3.35	45.16	103.45
SEm±	**2.32**	**0.77**	**0.77**	**1.03**	**1.37**	**0.09**	**1.41**	**3.11**
CD (P=0.05)	**NS**	**2.30**	**2.29**	**3.06**	**4.07**	**0.27**	**NS**	**NS**
Interaction (V × T)								
V_1T_1	84.52	31.43	23.09	39.06	53.34	2.20	47.38	105.50
V_1T_2	82.49	30.04	22.42	38.30	52.21	2.23	46.65	105.05
V_1T_3	80.48	25.61	20.15	34.91	47.75	2.91	44.96	102.01
V_1T_4	79.23	21.40	19.26	33.75	45.33	3.44	44.02	100.93
V_1T_5	77.05	19.40	19.01	31.40	41.92	3.69	43.67	100.15
V_2T_1	78.62	26.72	21.33	36.51	49.64	2.52	51.71	112.61
V_2T_2	77.50	24.24	20.80	36.10	48.44	2.66	50.80	111.47
V_2T_3	76.44	23.28	18.09	33.08	44.61	2.78	48.09	108.96
V_2T_4	75.07	21.58	17.52	31.85	42.38	2.86	47.29	107.42
V_2T_5	74.16	19.52	17.05	29.55	40.67	3.03	46.66	106.76
Mean	**78.56**	**24.32**	**19.87**	**34.45**	**46.63**	**2.77**	**47.12**	**106.09**
SEm±	**3.27**	**1.09**	**1.09**	**1.46**	**1.94**	**0.13**	**2.00**	**4.41**
CD (P=0.05)	**NS**	**3.25**	**NS**	**NS**	**NS**	**0.38**	**NS**	**NS**
CV (%)	**9.25**	**8.79**	**9.52**	**7.32**	**7.20**	**8.07**	**7.35**	**8.19**

Among the different seed rates, T_1 (75 kg/ha) recorded maximum field emergence (81.57 %), highest plant stand establishment (29.08/m ^{2}), highest plant height at 30, 60 DAS and harvest (22.71, 37.79 and 51.49 cm), lower number of branches per plant (2.38), more days to 50% flowering (49.55) and days to maturity (109.05) which is closely followed by T_2 (67.5 kg/ha) [field emergence (80.00 %), plant stand establishment (27.14/m ^{2}), plant height at 30, 60 DAS and harvest (21.61, 37.20 and 50.33 cm), number of branches per plant (2.42), days to 50% flowering (48.72) and days to maturity (108.26)]. Minimum field emergence (75.61 %), lowest plant stand establishment (19.46/m ^{2}), lowest plant height at 30, 60 DAS and harvest (18.03, 30.47 and 41.29 cm), more number of branches per plant (3.35), less days to 50% flowering (45.16) and days to maturity (103.45) were recorded at T_5 (45 kg/ha). Among the interaction, V_1T_1 recorded maximum field emergence (84.52 %), highest plant stand establishment (31.43/m ^{2}), highest plant height at 30, 60 DAS and harvest (23.09, 39.06 and 53.34 cm) than V_2T_5 [field emergence (74.16 %), plant stand establishment (19.40/m ^{2}), plant height at 30, 60 DAS and harvest (17.05, 29.55 and 40.67 cm)] where V_1T_5 took less number days to 50% flowering (43.67) and days to maturity (100.15) than V_2T_1.

The treatment T_1 (75 kg/ha) was found statistically on par with T_2 (67.5 kg/ha) suggest that even by reducing seed rate by 10 percent than recommended seed rate achieve similar vegetative growth. The results are in same line with studies of Kumar *et al.* (2018) who reported the superior field emergence, plant stand, and growth in *Super Annigeri-1* may be attributed to its higher seed vigor, better germination capacity, and genetic potential for early establishment. Similarly, Apte *et al.* (2014) also documented that increased plant height at higher seed rates (75 kg/ha) results from inter-plant competition for light, inducing elongation growth. Fewer branches per plant under dense stands occur due to shading and competition for nutrients and light, which suppress lateral bud development was documented by Singh *et al.* (2010). Thus, varietal traits and plant density–induced microclimatic variations collectively influence chickpea growth behavior.

The findings in table 2 indicates the effect of optimum seed rate on yield and yield attributes of chickpea. Among the two varieties, Super Annigeri-1 recorded a greater number of pods per plant (52.20), pod yield (3010 kg/ha), seed yield (1838 kg/ha), graded seed yield (1661 kg/ha) and seed recovery (89.41 %) compared to Phule Vikrant [pods per plant (48.35), pod yield (2808 kg/ha), seed yield (1705 kg/ha), graded seed yield (1549 kg/ha) and seed recovery (84.18 %)]. Among the different seed rates, T_1 (75 kg/ha) recorded lower number of pods per plant (41.10), highest pod yield (3280 kg/ha), highest seed yield (1925 kg/ha), highest graded seed yield (1813) and lesser seed recovery (82.02 %) which is closely followed by T_2 (67.5 kg/ha) [Number of pods per plant (44.85), pod yield (3207 kg/ha), seed yield (1917 kg/ha), graded seed yield (1765 kg/ha) and seed recovery (84.83 %)]. Higher number of pods per plant (58.76), lowest pod yield (2559 kg/ha), lowest seed yield (1600 kg/ha), lowest graded seed yield (1403 kg/ha) and greater seed recovery (92.87 %) were recorded at T_5 (45 kg/ha). Among the interaction, V_1T_1 recorded highest pod yield (3401 kg/ha), highest seed yield (2021 kg/ha) and highest graded seed yield (1887 kg/ha) than V_2T_5 [pod yield (2499 kg/ha), seed yield (1560 kg/ha) and graded seed yield (1397 kg/ha)].

Table 2 : Effect of optimum seed rate on yield and yield attributes of chickpea

Treatments	Number of pods per plant	Pod yield (kg/ha)	Seed yield (kg/ha)	Graded seed yield (kg/ha)	Seed recovery (%)
Varieties (V)					
V_1–SA_1	52.20	3010	1838	1661	89.41
V_2–Phule Vikrant	48.35	2808	1705	1549	84.18
SEm±	**1.03**	**63.84**	**36.68**	**36.35**	**1.579**
CD (P=0.05)	**3.07**	**189.69**	**108.98**	**108.00**	**4.692**
Different seed rates (T)					
T_1 -75kg/ha	41.10	3280	1925	1813	82.02
T_2-67.5kg/ha	44.85	3207	1917	1765	84.83
T_3 -60 kg/ha	49.62	2854	1742	1574	86.62
T_4-52.5kg/ha	55.79	2644	1672	1470	91.65
T_5 -45 kg/ha	58.76	2559	1600	1403	92.87
SEm±	**1.63**	**100.95**	**57.99**	**57.47**	**1.70**
CD (P=0.05)	**4.25**	**299.92**	**172.31**	**170.76**	**4.72**
Interaction (V × T)					
V_1T_1	40.33	3401	2021	1887	84.04
V_1T_2	44.35	3324	2013	1844	88.05
V_1T_3	53.16	2977	1798	1635	87.37
V_1T_4	59.84	2726	1716	1530	93.46
V_1T_5	63.52	2620	1640	1410	94.15
V_2T_1	41.93	3160	1829	1739	78.01
V_2T_2	45.21	3089	1821	1685	79.60
V_2T_3	47.25	2730	1686	1512	81.87
V_2T_4	51.64	2562	1629	1410	89.84
V_2T_5	53.87	2499	1560	1397	91.59
Mean	**50.3**	**2909**	**1771**	**1605**	**86.80**
SEm±	**2.31**	**142.76**	**82.02**	**81.28**	**3.53**
CD (P=0.05)	**6.06**	**NS**	**NS**	**NS**	**NS**
CV (%)	**7.96**	**8.50**	**8.02**	**8.77**	**7.05**

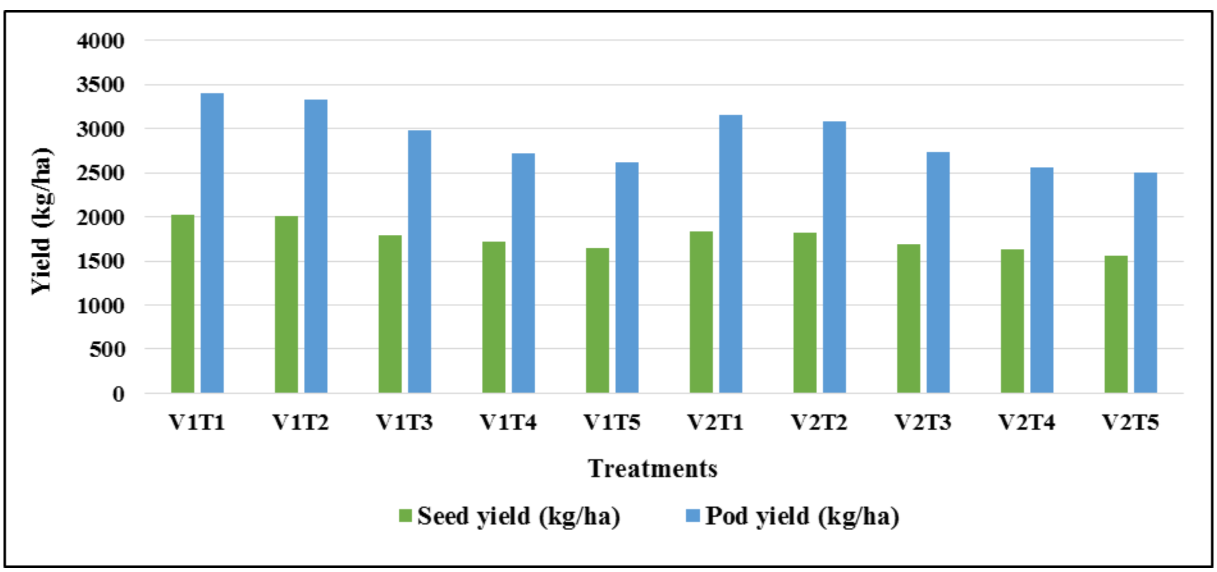


Fig. 1 : Seed yield and pod yield of chickpea influenced by different seed rates

V_1T_1:75 kg/ha **V_1T_5:45 kg/ha**

Plate 1 : Effect of different seed rates on number of pods per plant in chickpea

The variation in seed yield and its components among seed rates and varieties in chickpea can be attributed to differences in plant density and competition for growth resources. Higher seed rates (75 and 67.5 kg/ha) resulted in greater pod and seed yield per unit area due to higher plant population, even though the number of pods per plant and seed recovery decreased because of increased intra-specific competition for light, nutrients, and moisture, limiting individual plant productivity. Conversely, lower seed rates (45–52.5 kg/ha) improved the number of pods per plant and seed recovery percentage as plants received better light penetration, aeration, and nutrient availability, enhancing photosynthetic efficiency and assimilate translocation to developing seeds.

The results are in line with findings of Saxena and Johansen (1990)**,** who observed that reduced plant density in chickpea improved pod set and seed filling and by Chavan *et al.* (2014)**,** who noted that optimum seed rate and wider spacing enhanced photosynthetic efficiency and seed development. Moreover, the superior performance of Super Annigeri-1 may be due to its better genetic potential for assimilate partitioning and sink strength, leading to higher pod yield and seed recovery, as also supported by Singh *et al.* (2017)**,** who found significant varietal differences in seed yield potential under varying plant densities.

Effectiveness of optimization of seed rate on seed quality

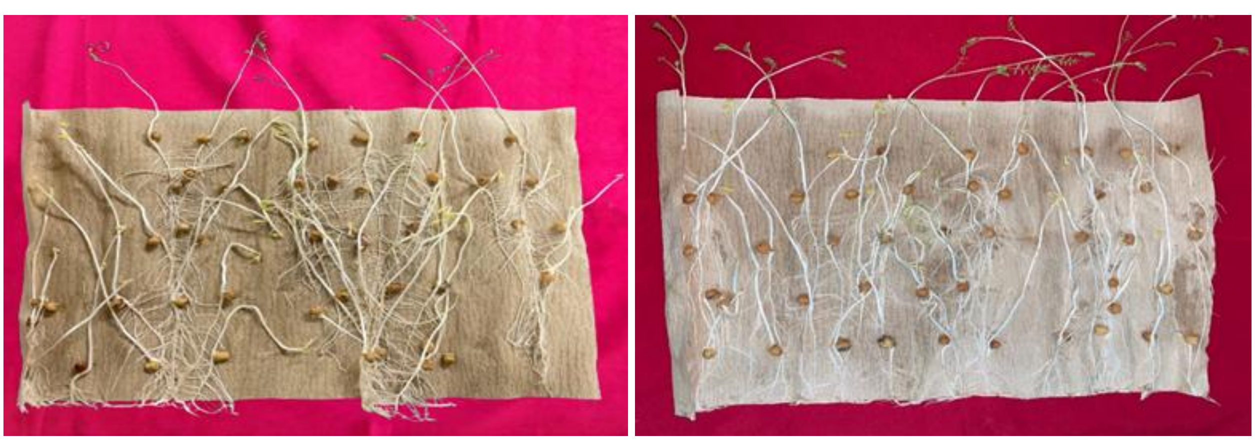
Table 3 represents the seed quality parameters of chickpea. Among the two varieties, Super Annigeri-1 recorded maximum hundred seed weight (24.11 g), highest seed thickness (6.74 mm), maximum seed germination (92.20 %), faster speed of germination (24.56), greater seedling vigour index I (3410) and seedling vigour index II (6172) compared to Phule Vikrant [Hundred seed weight (23.13 g), seed thickness (6.43 mm), seed germination (90.25 %), speed of germination (23.31), seedling vigour index I (2763) and seedling vigour index II (5950)]. Among the different seed rates, T_5 (45 kg/ha) recorded maximum hundred seed weight (26.01 g), highest seed thickness (6.82 mm), maximum seed germination (93.25 %), faster speed of germination (25.37), greater seedling vigour index I (3318) and seedling vigour index II (6349) where minimum hundred seed weight (21.97 g), lowest seed thickness (6.31 mm), minimum seed germination (88.54 %), slower speed of germination (25.37), lesser seedling vigour index I (2890) and seedling vigour index II (5754). Among the interaction, V_1T_5 recorded maximum hundred seed weight (27.72 g), highest seed thickness (6.90 mm), maximum seed germination (93.70 %), faster speed of germination (25.83), greater seedling vigour index I (3732) and seedling vigour index II (6403) and V_2T_1 minimum hundred seed weight (21.85 g), lowest seed thickness (6.01 mm), minimum seed germination (87.12 %), slower speed of germination (21.02), lesser seedling vigour index I (2636) and seedling vigour index II (5668).

The variation in seed quality parameters among different seed rates and varieties of chickpea is primarily influenced by the degree of inter-plant competition, seed filling efficiency and physiological maturity. Lower seed rates (45–52.5 kg/ha) produced seeds with greater size, thickness, germination and vigour indices due to reduced competition for light, nutrients, and assimilates, which allowed better translocation of photosynthates to developing seeds and improved seed reserve accumulation. In contrast, higher seed rates (75 and 67.5 kg/ha) led to smaller, less vigorous seeds because of overcrowding and limited resource availability during seed development.

The results are in line with the findings of Saxena and Johansen (1990)**,** who observed that lower plant densities in chickpea enhanced seed filling and seed weight and by Chavan *et al.* (2014)**,** who found that optimum spacing improved seed size and vigour due to better light interception and assimilate partitioning. The superior performance of Super Annigeri-1 compared to Phule Vikrant may be attributed to its genetic potential for efficient assimilate translocation and greater sink strength, resulting in heavier seeds with higher germination and vigour, as also confirmed by Singh *et al.* (2017)**.** Similarly, Ahlawat *et al.* (2016) and Ali *et al.* (2015) reported that reduced plant density and favorable genotypes produced physiologically mature, nutrient-rich seeds with superior germination and vigour indices.

Table 3 : Influence of optimum seed rate on seed quality parameters of chickpea

Treatments	Hundred seed weight (g)	Seed thickness (mm)	Seed germination (%)	Speed of germination	Seed vigour index-I	Seed vigour index- II
Varieties (V)						
V_1–SA_1	25.11	6.74	92.20	24.56	3410	6172
V_2–Phule Vikrant	23.13	6.43	90.25	23.31	2763	5950
SEm±	**0.22**	**0.05**	**0.64**	**0.17**	**26.0**	**72.2**
CD (P=0.05)	**0.65**	**0.14**	**1.88**	**0.50**	**76.6**	**213.0**
Different seed rates (T)						
T_1 -75kg/ha	21.97	6.31	88.54	22.31	2890	5754
T_2-67.5kg/ha	22.94	6.40	89.89	23.14	2936	5939
T_3 -60 kg/ha	24.40	6.65	91.87	24.16	3014	6100
T_4-52.5kg/ha	25.28	6.75	92.57	24.69	3277	6162
T_5 -45 kg/ha	26.01	6.82	93.25	25.37	3318	6349
SEm±	**0.35**	**0.07**	**1.01**	**0.27**	**41.0**	**114.1**
CD (P=0.05)	**1.02**	**0.21**	**2.97**	**0.80**	**121.1**	**336.7**
Interaction (V × T)						
V_1T_1	22.09	6.61	89.96	23.59	3144	5841
V_1T_2	23.00	6.68	91.26	24.06	3224	6085
V_1T_3	25.63	6.72	92.91	24.17	3280	6217
V_1T_4	27.11	6.81	93.15	25.13	3672	6312
V_1T_5	27.72	6.90	93.70	25.83	3732	6403
V_2T_1	21.85	6.01	87.12	21.02	2636	5668
V_2T_2	22.87	6.12	88.52	22.22	2649	5794
V_2T_3	23.16	6.58	90.83	24.14	2747	5984
V_2T_4	23.45	6.70	91.98	24.26	2881	6012
V_2T_5	24.30	6.74	92.80	24.91	2904	6295
Mean	**24.12**	**6.59**	**91.22**	**23.94**	**3087**	**6061**
SEm±	**0.49**	**0.10**	**1.42**	**0.38**	**58.1**	**161.4**
CD (P=0.05)	**1.44**	**0.30**	**NS**	**1.13**	**171.3**	**NS**
CV (%)	**3.51**	**3.96**	**3.71**	**4.76**	**3.3**	**4.6**



V_1T_1: 75 kg/ha **V_1T_2: 67.5 kg/ha**

Plate 2 : Impact of different seed rates on germination (%) in chickpea

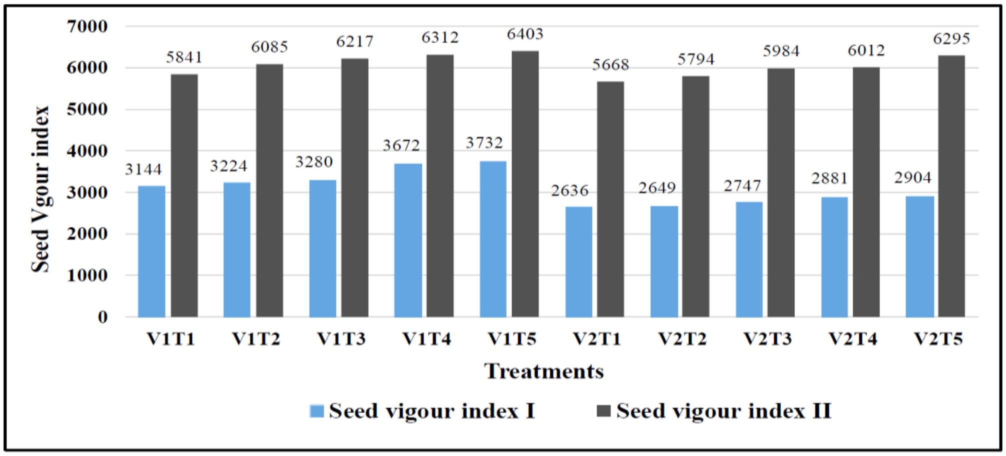


Fig. 2 : Influence of different seed rates on seed vigour index-I and seed vigour index- II in chickpea

Data in table 4 pertains biochemical properties of chickpea seeds. Among the two varieties, Super Annigeri-1 recorded highest seed protein content (22.18 %), total dehydrogenase activity (0.94) and peroxidase activity (0.65) compared to Phule Vikrant [seed protein content (19.80 %), total dehydrogenase activity (0.82) and peroxidase activity (0.46)]. Among the different seed rates, highest seed protein content (22.00 %), total dehydrogenase activity (0.95) and peroxidase activity (0.64) were recorded at T_5 (45 kg/ha) where lowest seed protein content (19.97 %), total dehydrogenase activity (0.80) and peroxidase activity (0.47) were recorded at T_1 (75 kg/ha). Among the interaction, V_1T_5 recorded highest seed protein content (23.25 %), total dehydrogenase activity (0.98) and peroxidase activity (0.75) and V_2T_1 lowest seed protein content (18.86 %), total dehydrogenase activity (0.72) and peroxidase activity (0.39).

The variation in seed biochemical parameters such as protein content, total dehydrogenase and peroxidase activity in chickpea is mainly due to genetic potential and resource availability influenced by seed rate. Super Annigeri-1 showed higher seed protein and enzyme activities than Phule Vikrant owing to its superior genetic capacity for nitrogen assimilation, seed filling and antioxidant enzyme synthesis, as also reported by Rahman *et al.* (2008). Higher protein and enzyme activity at the lowest seed rate (45 kg/ha) may result from reduced competition, allowing greater nutrient uptake and metabolic efficiency, whereas higher seed rates cause nutrient limitation and lower biochemical activity. Sharma *et al.* (2020) similarly found that lower plant density enhances seed vigour and quality.

Table 4 : Effect of optimum seed rate on seed biochemical parameters of chickpea

Treatments	Protein content (%)	Total dehydrogenase activity (OD at A480)	Peroxidase activity (OD at A_{436})
Varieties (V)			
V_1–SA_1	22.18	0.94	0.65
V_2–Phule Vikrant	19.80	0.82	0.46
SEm±	**0.18**	**0.008**	**0.005**
CD (P=0.05)	**0.54**	**0.023**	**0.015**
Different seed rates (T)			
T_1 -75kg/ha	19.97	0.80	0.47
T_2-67.5kg/ha	20.31	0.83	0.53
T_3 -60 kg/ha	21.10	0.90	0.55
T_4-52.5kg/ha	21.59	0.92	0.59
T_5 -45 kg/ha	22.00	0.95	0.64
SEm±	**0.29**	**0.012**	**0.008**
CD (P=0.05)	**0.86**	**0.037**	**0.023**
Interaction (V × T)			
V_1T_1	21.08	0.87	0.55
V_1T_2	21.56	0.92	0.62
V_1T_3	22.36	0.94	0.64

V_1T_4	22.66	0.96	0.69
V_1T_5	23.25	0.98	0.75
V_2T_1	18.86	0.72	0.39
V_2T_2	19.07	0.74	0.44
V_2T_3	19.84	0.85	0.45
V_2T_4	20.52	0.89	0.49
V_2T_5	20.74	0.91	0.52
Mean	**20.99**	0.88	0.55
SEm±	**0.41**	**0.018**	**0.011**
CD (P=0.05)	**NS**	**0.052**	**0.033**
CV (%)	**3.40**	**3.47**	**3.46**

Cost-Benefit ratio of optimum seed rate

The benefit–cost (B:C) ratio, which reflects the profitability of the system, further confirmed the economic advantage of a 10 % lower seed rate. The highest B:C ratio (2.82) was achieved in V_1T_2, which was comparable with V_1T_1 (2.76). In V_2, a similar trend was observed where V_2T_2 recorded a B:C ratio of 2.45, marginally higher and on par with 2.40 at V_2T_1. These results clearly indicate that a seed rate of 67.5 kg/ha (T_2) produced gross and net returns and B:C ratio equivalent to the recommended 75 kg/ha (T_1) in both varieties, with slightly lower cost of cultivation, thereby proving economically more efficient. Similar findings were reported by Sethi *et al.* (2015), who observed that slightly reduced seed rates in chickpea improved net economic returns without yield penalty.

Table 5 : Economics of chickpea influenced by optimum seed rate

Treatment Details	Cost of Cultivation (Rs/ha)	Gross returns (Rs/ha)	Net returns (Rs/ha)	B:C ratio
V_1T_1	61795	232361	170566	2.76
V_1T_2	60625	231461	170836	2.82
V_1T_3	59455	206793	147338	2.48
V_1T_4	58285	197352	139067	2.39
V_1T_5	57115	188586	131471	2.30
V_2T_1	61795	210289	148494	2.40
V_2T_2	60625	209363	148738	2.45
V_2T_3	59455	193879	134424	2.26
V_2T_4	58285	187301	129016	2.21
V_2T_5	57115	179400	122285	2.14

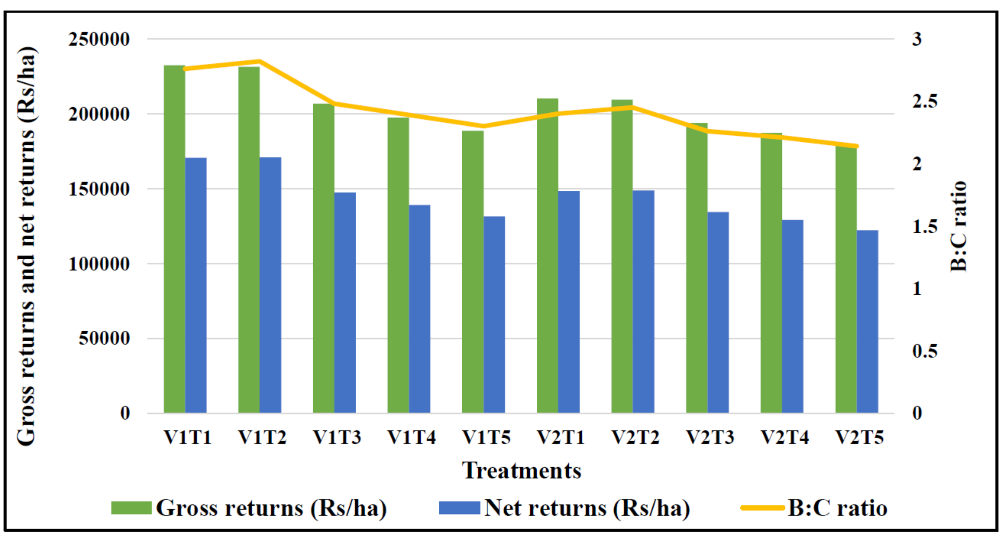


Fig. 3 : Economics of chickpea influenced by optimum seed rate

Conclusion

The present study clearly demonstrated that optimizing the seed rate in chickpea significantly influences plant growth, yield, seed quality and economic returns. Among the varieties, Super Annigeri-1 consistently outperformed Phule Vikrant in terms of growth, yield, physiological vigour and biochemical quality owing to its superior genetic potential and seed vigour. Although the recommended seed rate (75 kg/ha) produced the highest yield per unit area, a 10 % reduction in seed rate (67.5 kg/ha) achieved statistically comparable yield and seed quality with a higher benefit–cost ratio, indicating greater input efficiency. Lower seed rates (45–52.5 kg/ha) enhanced individual seed size, protein content and vigour due to reduced interplant competition but resulted in reduced total yield. Hence, a seed rate of 67.5 kg/ha is optimal for balancing productivity, seed quality and profitability in chickpea, particularly for the variety Super Annigeri-1 under the given agro-ecological conditions.

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