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# Growth and yield variation in chia (*Salvia hispanica*) caused by planting method and density

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## ABSTRACT

An experiment was conducted at Central Research Farm, Gayeshpur, Nadia under BCKV, West Bengal to assess the impact of plant density and planting methods on growth, yield and quality attributes of chia (*Salvia hispanica* L.) grown during winter (*rabi*) seasons of 2019–20 and 2020–21. Treatments were distributed in split-plot design, with 2 establishment methods ($M_1$, direct sowing and $M_2$, Transplanting) in main plots and 4 planting density ($S_1$, 60 cm × 50 cm = 33,333 plants/ha; $S_2$, 50 cm × 50 cm = 40,000 plants/ha; $S_3$, 50 cm × 25 cm = 80,000 plants/ha; $S_4$, 50 cm × 20 cm = 1,00,000 plants/ha) in sub-plots. Crop under direct sowing with closer spacing (50 cm × 20 cm) had the greater number of primary branch (15.7/plant), primary branch length (38.4 cm) and main inflorescence length (25.9 cm), thereby reflecting superiority of this treatment combination over others. The same treatment combination produced significantly the highest grain (671.7 kg/ha), stem (1109.4 kg/ha) and husk yield (375.2 kg/ha), which led to increase harvest index (31.2). The greatest economic response in terms of gross return ($228.4 \times 10^3$ ₹/ha), net return ($166.3 \times 10^3$ ₹/ha) and B: C ratio (3.67) was recorded in crop under the same treatment combination. Based on quadratic regression equation, the optimum plant density of chia was calculated as 71,428 plants/ha. Thus, direct seed sowing at a density of 71,428 plants/ha (spacing ~ 55 cm × 25 cm) can be done for chia cultivation during *rabi* season in West Bengal condition.

**Keywords**: Economics, Oil content, Plant density, Productivity, Spacing

Chia (*Salvia hispanica* L.) is an annual herb of medium duration (103–136 days) belongs to the Lamiaceae family. It is a short-day plant with strong sensitivity to photoperiod and temperature (Baginsky *et al.* 2016). Various types of soil are suitable for cultivation of this crop, but plants do best in sandy and well-drained soil with optimal *p*H of 6.0–8.5 and are adapted to low nutrient concentrations (Yeboah *et al.* 2014). In recent years, chia seeds have become very popular for its nutritional merits which consisted of 20–34% fat, 60% α-linolenic and 20% linoleic acids (Mohd Ali *et al.* 2012). Other valuable constituents of chia seed include 16–26% protein (mainly prolamins), 23–41% dietary fiber, ample quantities of vitamins (mostly B complex), minerals (mainly Ca, Mg, P and K), extraordinary mucilaginous fibre and antioxidant (Peiretti and Gai 2009). Chia seeds show anti-inflammatory and anti-diabetic properties, and also works well against cardiovascular diseases and hypertension (Amato *et al.* 2015).

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Chia, with wider adaptability to varied agro-climatic conditions, is considered as an alternative crop not only for maintaining food security but also to mitigate climate change effect (Herman *et al.* 2016). Till date, information on agronomic management effects on yield and seed quality of chia is very meagre. Research work conducted so far is mainly confined to study the impact of location, sowing dates and seed source. However, it is imperative to optimize planting density and develop ideal planting method for avoiding excessive crowding and thereby enabling the plants to utilize resources (land, sunlight, nutrients, water etc.) more efficiently (Rana *et al.* 2020). Yeboah *et al.* (2014) studied the sole effect of planting density or combined effect with planting method on chia, but under completely different growing situations. So, an ideal combination of planting method and density need to be established particularly for chia cultivation under West Bengal condition. Hence, the present study aimed at the effect of varied combinations of planting method and density on growth attributes, yield components, yield and seed quality of chia during *rabi* season in West Bengal condition.

## MATERIALS AND METHODS

The field study was carried out during winter (*rabi*) seasons of 2019–20 and 2020–21 (sub-tropical climate) at Central Research Farm, Gayeshpur, Nadia (Bidhan Chandra Krishi Viswavidyalaya), West Bengal. Maximum temperature was to the tune of 31.2–23.4°C in *rabi* 2019–20 and 33.2–24.8°C in *rabi* 2020–21, while minimum temperature was in the range of 18.8–11.3°C in *rabi* 2019–20 and 20.8–11.5°C in *rabi* 2020–21. Relative humidity was in the range of 94.0–47.8% in *rabi* 2019–20, and 91.5–35.0% in *rabi* 2020–21. During the cropping period (*rabi* season), 6.08 and 0.04 mm rainfall was recorded in 2019–20 and 2020–21, respectively. Hence, chia crop enjoyed congenial weather conditions and finally exhibited satisfactory growth and development during both the *rabi* seasons. The sandy loam soil of the experimental site had 7.08 *p*H, 0.48 dS/m EC, 0.9% organic carbon, 226.0 kg/ha available N, 45.5 kg/ha available P and 175.0 kg/ha available K.

The field layout was made as per split-plot design, with 2 methods of establishment ($M_1$, direct sowing and $M_2$, Transplanting) in main plots and 4 planting densities ($S_1$, 60 cm × 50 cm = 33,333 plants/ha; $S_2$, 50 cm × 50 cm = 40,000 plants/ha; $S_3$, 50 cm × 25 cm = 80,000 plants/ha; $S_4$, 50 cm × 20 cm = 1, 00,000 plants/ha) in sub-plots. There were total 8 treatment combinations (2 × 4), each replicated thrice. Individual plot size was 5 m × 3 m and 0.5 m wide gap was maintained in between two adjacent plots. In both the years of study, 5 kg chia seeds were sown per hectare on $29^{th}$ and $28^{th}$ November in the year of 2019 and 2020, respectively. As per fertilizer recommendation of the experimental location, 60 kg N, 30 kg $P_2O_5$ and 30 kg $K_2O$ per hectare was applied through urea, Single Super Phosphate (SSP) and Muriate of potash (MOP), respectively. Basal application (prior to sowing) of total amount of P and K fertilizers was made in each plot. Two equal (50% each) split applications of N fertilizer were done just before sowing and 30 days after sowing (DAS) or transplanting (DAT), respectively. Single irrigation just before sowing, given for both the establishment methods, supported better seed germination and crop establishment. The crop received two irrigations at 28 and 72 DAS, respectively. Two hoeing were done at 35 and 70 DAS to trigger the growth of crop. In both *rabi* seasons, there was no crop damage caused by pest and disease pathogens. Crops were harvested (128 DAS) at 3 cm above the ground level when spike turned brown colour and seeds became hard.

The average plant height and dry matter accumulation was recorded from 5 randomly selected plants in each plot. For estimating dry matter accumulation, the seed and plant samples were dried (at 65–70°C) in a hot-air oven for 2–3 days, till constant weights were attained. The leaf-weight relationship was used to determine leaf area index. Yield components were recorded at harvest from 5 randomly selected plants in each plot. After proper sun-drying, plants were threshed manually. Seeds were separated from the spike and dried subsequently to bring down the moisture content at 14.0%. Weight of seeds per plot was finally converted into seed weight per hectare. The plants (without grain) were sun-dried and then stem and husk yield were estimated. The harvest index was determined by the ratio of seed weight and total biomass (seed + stem + husk), and finally multiplied by 100. For determination of oil and crude protein content, standard procedure was followed (AOAC 2005). Oil and crude protein yield were calculated by multiplying their concentrations (%) with the seed yield (kg/ha), divided by 100. For determination of nutrient (NPK) status of post-harvest soil, standard procedures were followed. The economic viability of chia cultivation was assessed in terms of gross return, net return and benefit: cost ratio, taking into account the market prices of various inputs and outputs prevailed during cropping time.

Data obtained in the present study were analyzed following the analysis of variance (ANOVA) suitable for strip-plot design (Gomez and Gomez 1984). The significance of difference due to sources of variance was tested by error mean square (SEm±) at 0.05% probability level following Fisher Snedecor's 'F' test. For calculation of critical difference (CD) at 5% level of significance Fisher and Yates' tables were consulted. Bartlett's chi-square test was performed to test the homogeneity of variance over the two years. Lastly, logical conclusions were drawn based on pooled data.

*Regression analysis for development of quadratic equation*: To determine the optimum plant density of chia we used the polynomial quadratic regression equation model, $y = a - bx + cx^2$ (Fig 1). The quadratic equation was developed by computer-based Microsoft-Excel Programme (2007). The average values of seed yield per plant from the present study were plotted against the plant density per hectare (treatment-wise), as average yield increase of an individual plant is directly proportional to plant density (Reddy and Reddy 2020). A quadratic equation was obtained ($y = 7E\text{-}10x^2 - 0.0001x + 10.191$) by regression analysis with the highest value of $R^2$ (0.8151) using the above mentioned experimental data. Then the optimum plant density was worked out as:

$$PD_{opt}\ (No/ha) = -\ b/2c$$

where, $PD_{opt}$ = optimum plant density; and b and c are regression coefficients of quadratic equation.

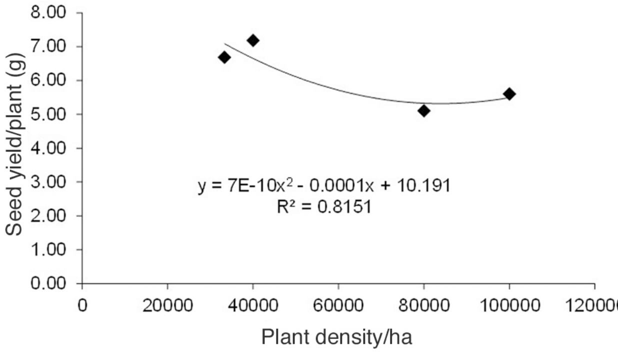


Fig 1 Functional relationship between plant density and seed yield of chia.

## RESULTS AND DISCUSSION

*Growth attributes*: Method of sowing exerted significant influence on measured growth attributes of chia, viz. plant height at 100 DAS/70 DAT, leaf area index (LAI) at 100 DAS/70 DAT, dry matter accumulation (DMA) at 100 DAS/70 DAT and crop growth rate (CGR) at 76–100 DAS/46–70 DAT (Table 1). Direct sowing resulted in taller plants (90.4 cm), than transplanted crop (68.5 cm). Similarly, direct seeded crop exhibited higher LAI (0.99), dry matter accumulation at 100 DAS/70 DAT (117.8 g/$m^2$) and CGR during 76–100 DAS/46–70 DAT (2.90 g/$m^2$/day) registering 76.8, 37.6 and 12.8% more than transplanted crop, respectively. Plant showed significant improvement in height (87.6 cm), LAI (1.30), DMA (125.9 g/$m^2$) at 100 DAS/70 DAT and CGR at 100 DAS/70 DAT (3.11 g/$m^2$/day) under high density planting (1,00,000 plants/ha at 50 cm × 20 cm spacing), accounting 21.7, 209.5, 53.7 and 26.4% more than low planting density (33,333 plants/ha at 60 cm × 50 cm spacing). There was hardly any negative effect of increasing plant density on measured growth attributes due to less intra-plant competition (Balem *et al.* 2014). When crops are planted at high densities, the efficiency of intercepted light is improved as a consequence of increased LAI (Rana *et al.* 2020). Such increase may be due to early canopy closer and improved light interception (Kamara *et al.* 2018). Moreover, dense plant stand produces higher biomass per unit area because of better use of soil and moisture (Mokhtarpour *et al.* 2013) and increased competition for light (Dawadi and Sah 2012). Plant height was unaffected by interaction effects. However, interaction effects were significant for LAI, dry matter accumulation and CGR. The crop had the maximum LAI (1.83), DMA (150.7 g/$m^2$) at 100 DAS/70 DAT and CGR at 100 DAS/70 DAT (3.43 g/$m^2$/day) under direct sowing with closer spacing (50 cm × 20 cm).

*Yield components*: Significant difference was observed in yield components of chia due to adoption of varied planting methods, except 1000-seed weight (Table 1). The crop under direct sowing recorded higher number of primary branches (13.1/plant), primary branch length (33.7 cm) and main inflorescence length (22.5 cm), registering 18%, 32.7% and 25.7% more than transplanted crop. All these measured yield components varied significantly when crop sown under varied planting densities (Table 1). The adoption of high density planting (1,00,000 plants/ha at 50 cm × 20 cm spacing) resulted significant increase in all three yield components, accounting 33%, 26.1% and 33.9% more than low planting density (33,333 plants/ha at 60 cm × 50 cm spacing) for no. of primary branches/plant, primary branch length and main inflorescence length, respectively. Interaction effects exerted significant influence on these yield components. Crop under direct sowing with closer spacing (50 cm × 20 cm) had the greater number of primary branches (15.7/plant), primary branch length (38.4 cm) and main inflorescence length (25.9 cm), thereby reflecting superiority of this treatment combination over others. Both main and interaction effects did not bring any significant changes in test weight (1000-seed weight).

Table 1 Effect of planting method and density on growth and yield contributing factors of chia grown in *rabi* season (pooled data of 2 years)

| Treatment | Growth attributes | | | | Yield contributing factors | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Plant height (cm) at 100 DAS/70 DAT | LAI at 100 DAS/70 DAT | DMA (g/$m^2$) at 100 DAS/ 70 DAT | CGR (g/ $m^2$/day) during 76–100 DAS/46–70 DAT | No. of primary branches/ plant | Length of primary branches (cm) | Length of main inflorescence (cm) | 1000-seed weight (g) | Seed yield (kg/ha) | Stem yield (kg/ha) | Husk yield (kg/ha) | Harvest index (%) |
| *Planting method* | | | | | | | | | | | | |
| $M_1$ | 90.4 | 0.99 | 117.8 | 2.90 | 13.1 | 33.7 | 22.5 | 1.235 | 422.9 | 793.3 | 246.1 | 29.7 |
| $M_2$ | 68.5 | 0.56 | 85.6 | 2.57 | 11.1 | 25.4 | 17.9 | 1.233 | 315.9 | 574.5 | 195.5 | 29.1 |
| SEm(±) | 2.86 | 0.00 | 0.66 | 0.04 | 0.12 | 0.65 | 0.32 | 0.00 | 6.96 | 10.81 | 1.51 | 0.12 |
| CD (P=0.05) | 17.03 | 0.02 | 4.05 | 0.24 | 0.74 | 4.16 | 1.91 | NS | 42.38 | 65.81 | 9.18 | NS |
| *Planting density* | | | | | | | | | | | | |
| $S_1$ | 72.0 | 0.42 | 81.9 | 2.46 | 10.6 | 26.1 | 17.4 | 1.233 | 222.6 | 400.7 | 149.8 | 28.8 |
| $S_2$ | 77.9 | 0.56 | 92.0 | 2.54 | 11.5 | 28.9 | 19.0 | 1.232 | 287.2 | 533.5 | 178.8 | 28.8 |
| $S_3$ | 80.0 | 0.80 | 106.8 | 2.84 | 12.3 | 30.3 | 21.2 | 1.234 | 408.1 | 728.4 | 235.3 | 29.6 |
| $S_4$ | 87.6 | 1.30 | 125.9 | 3.11 | 14.1 | 32.9 | 23.3 | 1.237 | 559.9 | 964.9 | 319.5 | 30.2 |
| SEm(±) | 1.57 | 0.03 | 2.24 | 0.11 | 0.25 | 0.82 | 0.48 | 0.002 | 8.43 | 14.85 | 4.13 | 0.12 |
| CD (P=0.05) | 5.49 | 0.10 | 6.90 | 0.34 | 0.76 | 2.56 | 1.47 | NS | 25.97 | 45.78 | 12.72 | 0.45 |

LAI, leaf area index; DMA, dry matter accumulation; CGR, crop growth rate; DAS, days after sowing; DAT, days after transplanting; NS, non-significant. Treatment details are given under Materials and Methods.

*Grain, stem and husk yield*: The crop grown with direct sowing out-yielded transplanted crop in terms of grain, stem and husk yield (Table 1). Significantly higher grain (422.9 kg/ha), stem (739.3 kg/ha) and husk yield (246.1 kg/ha) were obtained with direct seeded crop registering 33.9, 28.7 and 25.9% more than transplanted crops, respectively. Crops with higher planting density (1, 00,000 plants/ha at 50 cm × 20 cm spacing) gave significantly the highest grain (559.9 kg/ha), stem (964.9 kg/ha) and husk yield (319.5 kg/ha), accounting 151.5, 140.8 and 113.3% more than crops under low planting density (33,333 plants/ha at 60 cm × 50 cm spacing), respectively. Despite of increasing plant density, crops might have exposed to least resource-starved condition, and thereby produce maximum yield. Furthermore, yield of individual plant decreases with parallel increase of plant density; however, it may lead to increased yield per unit area (Kar *et al.* 2006). On the contrary, optimum plant stand exhibit proper resource utilization in soil, and thereby produces higher crop yield (Jat *et al.* 2017). In our study, harvest index (HI) was unaffected by planting method (Table 1). However, it was significantly influenced by planting densities. Crops under high planting density (1, 00,000 plants/ha at 50 cm × 20 cm spacing) had the highest HI (30.2), accounting 4.9% more than the HI of crops under low planting density (33,333 plants/ha at 60 cm × 50 cm spacing). Interaction effects were significant on grain yield, stem yield, husk yield and HI. Crops under direct sowing with higher planting density (1,00,000 plants/ha at 50 cm × 20 cm spacing) produced significantly higher grain yield (671.7 kg/ha), stem yield (1109.4 kg/ha), husk yield (375.2 kg/ha) and HI (31.2).

*Determination of optimum plant density*: Functional relationship between plant density and seed yield of chia was estimated as $y = 7E\text{-}10x^2 - 0.0001x + 10.191$ ($R^2 = 0.8151$) (Fig 1). The result indicated that the plant density effect on chia seed yield could be explained about 81% by this functional model. The optimum plant density of chia was derived as 71,428 plants/ha. Furthermore, the co-efficient also indicated that the increase of 1 plant/ha (beyond 71,428 plants/ha) would decrease the seed yield @$1 \times 10^{-4}$ g/plant. It again proved the fact that extremely dense stands suffer from inter-plant and intra-plant competition resulting in lower average seed yield/plant.

*Seed quality*: Planting methods brought about significant changes in quality parameters of chia seeds (Table 2). All the assessed quality parameters were found to be higher in seeds obtained from direct seeded crop, accounting 38.7, 92.9, 31.3 and 77.2% more oil content, oil yield, crude protein content and crude protein yield than those of transplanted crop, respectively. Seed oil content, oil yield, crude protein content and crude protein yield were significantly highest in crops grown under higher planting density (1,00,000 plants/ha at 50 cm × 20 cm spacing), registering 70.2, 342.7, 100.4 and 411.7% more than those of crops under low planting density (33,333 plants/ha at 60 cm × 50 cm spacing). Interaction effects on these seed quality parameters were found to be significant (Table 3). Crops under direct sowing with higher planting density (1,00,000 plants/ha at 50 cm × 20 cm spacing) produced seeds with significantly the highest quality traits. However, interaction effect did not cause any significant variation in crude protein content of chia seeds.

*Nutrient status of soil at crop harvest:* The soil *p*H at crop harvest was not significantly much affected by planting

Table 2 Effect of planting method and density on oil quality, post-harvest soil status and economics of chia grown in *rabi* season (pooled data of 2 years)

| Treatment | Oil quality | | | | Post-harvest soil status | | | | | Economics | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Oil content (%) | Oil yield (kg/ha) | Crude protein content (%) | Crude protein yield (kg/ha) | *p*H | Organic carbon (%) | Available N (kg/ha) | Available P (kg/ha) | Available K (kg/ha) | Gross return (× $10^3$ ₹/ha) | Net return (× $10^3$ ₹/ha) | B : C ratio |
| *Planting method* | | | | | | | | | | | | |
| $M_1$ | 28.3 | 129.8 | 38.2 | 176.3 | 6.75 | 0.28 | 196.2 | 29.0 | 143.8 | 143.8 | 81.7 | 2.32 |
| $M_2$ | 20.4 | 67.3 | 29.1 | 99.5 | 6.78 | 0.47 | 201.8 | 35.8 | 150.6 | 107.4 | 43.5 | 1.68 |
| SEm(±) | 0.65 | 4.54 | 0.62 | 1.13 | 0.015 | 0.011 | 0.37 | 0.32 | 0.64 | 2.36 | 2.36 | 0.04 |
| CD (P=0.05) | 3.96 | 27.66 | 3.76 | 6.89 | NS | 0.06 | 2.14 | 1.97 | 3.95 | 14.41 | 14.41 | 0.23 |
| *Planting density* | | | | | | | | | | | | |
| $S_1$ | 18.1 | 40.5 | 23.3 | 52.2 | 6.73 | 0.47 | 205.7 | 34.9 | 151.6 | 75.7 | 12.7 | 1.20 |
| $S_2$ | 22.3 | 64.8 | 28.9 | 84.8 | 6.81 | 0.42 | 200.7 | 33.4 | 147.3 | 97.7 | 34.7 | 1.55 |
| $S_3$ | 26.1 | 109.7 | 35.6 | 147.6 | 6.70 | 0.34 | 196.4 | 31.9 | 146.4 | 138.4 | 75.8 | 2.21 |
| $S_4$ | 30.8 | 179.3 | 46.7 | 267.1 | 6.83 | 0.28 | 193.2 | 29.4 | 143.4 | 190.4 | 127.4 | 3.03 |
| SEm(±) | 0.28 | 3.17 | 0.63 | 3.44 | 0.040 | 0.026 | 1.04 | 0.63 | 0.84 | 2.86 | 2.86 | 0.05 |
| CD (P=0.05) | 0.88 | 9.79 | 1.96 | 10.60 | NS | 0.08 | 3.21 | 1.95 | 2.58 | 8.83 | 8.83 | 0.14 |

N, nitrogen; P, phosphorus; K, potassium; B : C, benefit: cost; NS, non-significant. Treatment details are given under Materials and Methods.

Table 3 Interaction effect of planting method and density on growth, yield contributing factors, oil quality and economics of chia grown in *rabi* season (pooled data of 2 years)

| Treatment combination | LAI at 100 DAS/70 DAT | DMA (g/m²) at 100 DAS /70 DAT | CGR (g/m²/day) during 76–100 DAS/46–70 DAT | Branches/ plant | Seed yield (kg/ha) | Stem yield (kg/ha) | Husk yield (kg/ha) | Harvest index (%) | Oil content (%) | Oil yield (kg/ha) | Crude protein yield (kg/ha) | Gross return (× 10³ ₹/ ha) | Net return (× 10³ ₹/ ha) | B:C ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $M_1 \times S_1$ | 0.34 | 88.4 | 2.39 | 11.0 | 233.7 | 420.8 | 155.4 | 28.9 | 20.1 | 47.1 | 62.8 | 79.5 | 17.4 | 1.28 |
| $M_1 \times S_2$ | 0.44 | 102.9 | 2.42 | 12.4 | 313.5 | 609.9 | 184.9 | 28.3 | 25.5 | 79.9 | 108.6 | 106.6 | 44.5 | 1.71 |
| $M_1 \times S_3$ | 0.66 | 129.2 | 3.36 | 13.5 | 472.9 | 817.2 | 268.9 | 30.3 | 30.7 | 145.6 | 186.9 | 160.8 | 98.7 | 2.59 |
| $M_1 \times S_4$ | 0.77 | 150.7 | 3.43 | 15.7 | 671.7 | 1109.4 | 375.2 | 31.2 | 36.7 | 246.7 | 346.7 | 228.4 | 166.3 | 3.67 |
| $M_2 \times S_1$ | 0.34 | 75.5 | 2.51 | 10.2 | 211.5 | 380.7 | 144.2 | 28.7 | 16.1 | 33.9 | 41.5 | 71.9 | 8.0 | 1.12 |
| $M_2 \times S_2$ | 0.44 | 81.0 | 2.65 | 10.6 | 260.9 | 457.1 | 172.6 | 29.3 | 18.9 | 49.6 | 60.9 | 88.7 | 24.9 | 1.39 |
| $M_2 \times S_3$ | 0.66 | 84.5 | 2.32 | 11.1 | 343.2 | 639.5 | 201.5 | 28.9 | 21.5 | 73.7 | 108.2 | 116.7 | 52.8 | 1.82 |
| $M_2 \times S_4$ | 0.77 | 101.3 | 2.79 | 12.4 | 448.0 | 820.5 | 263.8 | 29.3 | 24.9 | 111.8 | 187.4 | 152.3 | 88.5 | 2.38 |
| M × S | | | | | | | | | | | | | | |
| SEm(±) | 0.007 | 1.33 | 0.08 | 0.24 | 13.93 | 21.62 | 3.02 | 0.26 | 1.30 | 9.09 | 2.26 | 4.73 | 4.73 | 0.08 |
| CD (P=0.05) | 0.143 | 9.76 | 0.48 | 1.07 | 36.73 | 64.74 | 17.99 | 0.65 | 1.25 | 13.85 | 14.99 | 12.49 | 12.49 | 0.19 |
| S × M | | | | | | | | | | | | | | |
| SEm(±) | 0.040 | 2.52 | 0.14 | 0.32 | 12.45 | 21.16 | 5.27 | 0.23 | 0.74 | 5.98 | 4.36 | 4.23 | 4.23 | 0.07 |
| CD (P=0.05) | 0.122 | 8.62 | 0.43 | 1.18 | 38.97 | 65.36 | 16.09 | 0.61 | 3.20 | 21.44 | 13.31 | 13.25 | 13.25 | 0.20 |

LAI, leaf area index; DMA, dry matter accumulation; CGR, crop growth rate; DAS, days after sowing; DAT, days after transplanting; B:C, benefit: cost; NS, non-significant. Treatment details are given under Materials and Methods.

method and density (Table 2). However, soil organic carbon, available N, available P and available K status were found to be significantly higher in plots having transplanted crop, accounting 67.9, 2.9, 23.4 and 4.7% more than the soil status in plots having direct seeded crop, respectively. Values of all these soil characteristics in plots decreased with as the plant density increased. Soil in plots occupied by crops with low planting density (33,333 plants/ha at 60 cm × 50 cm spacing) had significantly higher OC, available N, available P and available K content, accounting 67.9, 6.5, 18.7 and 5.7% more than the soil properties in plots occupied by crops with high planting density (1,00,000 plants/ha at a spacing of 50 cm × 20 cm). This is attributed to progressive increase of NPK uptake by the crop which ultimately reduced the available status of those nutrients in post-harvest soil under higher plant density (Rana *et al.* 2020). Interaction effect did not bring any significant variation in soil chemical properties at crop harvest (Table 3).

*Economics of chia cultivation*: The economic benefit of chia cultivation, in terms of gross return (GR), net return (NR) and benefit: cost (B:C) ratio, was observed to vary with studied factors namely planting method and density (Table 2). Crop under direct sowing fetched significantly higher GR (143.8 × 10³ ₹/ha), NR (81.7 × 10³ ₹/ha) and BCR (2.32), accounting 33.9, 87.8 and 38.1% more than those of transplanted crop, respectively. This obvious response is due to the fact that higher yield was realized in the former case. On the other hand, the maximum GR (190.4 × 10³ ₹/ha), NR (127.4 × 10³ ₹/ha) and BCR (3.03) were recorded with crops grown at higher density (1,00,000 plants/ha at 50 cm × 20 cm spacing), accounting 151.5, 903.1 and 152.5% more than the crops planted at low density (33,333 plants/ha at 60 cm × 50 cm spacing). Interaction effect exerted significant effect on above mentioned economic indicators. The greatest response in terms of GR (228.4 × 10³ ₹/ha), NR (166.3 × 10³ ₹/ha) and BCR (3.67) was recorded in crop under direct sowing with higher planting density (1,00,000 plants/ha at 50 cm × 20 cm spacing).

Conclusively, the functional relationship between plant density and seed yield of chia was estimated as $y = 7E\text{-}10x^2 - 0.0001x + 10.191$ ($R^2 = 0.8151$) and the optimum plant density of chia was derived as 71,428 plants/ha. To accommodate same number of plants/ha, the seeds must be sown at 55 cm × 25 cm spacing. Thus, direct sowing of seeds at a density of 71,428 plants/ha (spacing ~ 55 cm × 25 cm) can be done for chia cultivation during *rabi* season in West Bengal condition.

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