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Crop growth indices and yield as influenced by different agronomic practices in chia (*Salvia hispanica* L.)

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Abstract
A study was carried out to check the performance of chia under different agronomic practices at ZARS, V. C. Farm, Mandya, Karnataka for a period of two years (2020 and 2021). The experiment was carried out in a randomized complete block design (RCBD) with factorial design (three replications). The row spacing of 45 × 15 cm^2 recorded higher seed yield (843 kg/ha), NAR (8.26 $g/cm^2/day \times 10^{-4}$) at 30 – 60 DAS, CGR (6.73, 14.28 and 26.58 $g/cm^2/day$, respectively at 0 – 30, 30 – 60 and 60 – 90 DAS), SLA (59.02, 50.76 and 54.25 cm^2/g, respectively at 30, 60 and 90 DAS) and quality parameters *viz.* crude protein, oil, zinc and iron content (22.62%, 30.02%, 3.65 mg 100 g^{-1} and 6.27 mg 100 g^{-1}, respectively). While 60 × 15 cm^2 obtained higher NAR (7.13 $g/cm^2/day \times 10^{-4}$) at 60 – 90 DAS and LPR (1.2206, 2.5946 and 1.9364 leaf/day, respectively). The application of 100% N equivalent through compost and jeevamrutha at sowing and 30 DAS recorded superior seed yield (972 kg/ha), NAR (8.50 $g/cm^2/day \times 10^{-4}$ at 30 – 60 DAS), CGR (7.44, 14.12 and 26.01 $g/cm^2/day$, respectively at 0 – 30, 30 – 60 and 60 – 90 DAS), LPR (1.3911, 2.7477 and 2.2612 leaf/day, respectively) and quality parameters (23.42%, 31.47%, 3.94 mg 100 g^{-1} and 6.97 mg 100 g^{-1}, respectively), while 75% N equivalent through compost and jeevamrutha at sowing and 30 DAS noted higher NAR at 60 – 90 DAS (7.46 $g/cm^2/day \times 10^{-4}$). Whereas, 75% N equivalent through compost registered higher SLA (69.47, 59.29 and 60.65 cm^2/g, respectively at 30, 60 and 90 DAS). Interaction effect was found non-significant.

Keywords: Chia, crop growth rate, net assimilation rate, specific leaf area and leaf production rate

Introduction
Potential crops, alternatively referred to as underutilized, orphaned, or neglected crops, are plants that serve as crucial species in harsh environmental conditions, offering significant nutritional value for both current and future human needs. Chia (*Salvia hispanica* L.), a member of the *Lamiaceae* family, is among these potential crops. Originating from regions in Mexico and Guatemala, Chia has been rediscovered as a superfood, nutraceutical, or functional food (Chaitanya *et al*., 2022) [6]. The term 'Chia' or 'Chien' is derived from Spanish, meaning 'Oily' (Kulczynski *et al*., 2019) [15].
The Chia crop remains unfamiliar to many in the farming community, yet there is significant potential within the Indian market to combat malnutrition. In India, Chia cultivation has been observed in certain areas of Himachal Pradesh and the Himalayan region (Peperkamp, 2015) [24]. The introduction of Chia (*Salvia hispanica* L.) in Karnataka by the Central Food Technological Research Institute (CFTRI) to farmers near Mysuru, Chamarajanagar, Belgaum and other districts has sparked interest, with cultivation now expanding to neighboring states. This adoption of the new crop is driven by its promising returns and favorable buy-back schemes (Chaitanya *et al*., 2022) [6].
Plant development is significantly influenced by factors such as plant stand, planting arrangement, soil fertility and soil moisture. Among these, spacing emerges as a pivotal factor impacting plant development (Rajput *et al*., 1993 and Sanodiya *et al*., 2022) [25,30]. Optimal row spacing is crucial to ensure thick plant populations receive adequate light for photosynthesis and are less susceptible to diseases. Conversely, insufficient plant populations can lead to decreased yields. Thus, achieving an optimal population is essential for maximizing yield (Bashir, 1994) [4].

The leaf canopy population, being the primary organ for photosynthesis, is influenced by nitrogen levels. Proper nitrogen application rates can promote a higher Leaf Area Index (LAI) in the crop canopy. Furthermore, nitrogen plays a significant role in seed quality formation (Zhang *et al*., 2020) [36]. Considering these factors, this study aims to investigate the effects of row spacing and organic nutrient sources on the yield and growth indices of chia.

Materials and Methods

The study was carried out at Zonal Agricultural Research Station (ZARS), V. C. Farm, Mandya (G-block), Karnataka, spanning two years from September to December in 2020 and 2021 (*kharif* season). The aim was to assess the impact of spacing and nitrogen levels on the yield and growth indices of chia. The variety of chia utilized in the experiment was a local cultivar. This annual herb typically reaches heights of up to 1.2 meters, featuring opposite leaves measuring 4-8 cm in length and 3-5 cm in width. The plant produces cluster of purple or white flowers at the end of each branch. Its seeds are small ovals, approximately 1 mm in diameter, exhibiting a mottled coloring of brown, grey, black and white. Notably, these seeds are hydrophilic, capable of absorbing up to twelve times their weight when immersed in liquid, and develop a mucilaginous coating. It possesses a yield potential ranging from 4 to 5 quintals per hectare, typically achieved within a crop duration of 100 to 120 days.

The experiment consisted of two sets of treatments namely A) row spacing *viz*., i) 45 × 15 cm^2 (S_1), ii) 60 ×15 cm^2 (S_2) and B) six nitrogen levels i) 75% N equivalent through compost (N_1), ii) 100% N equivalent through compost (N_2), iii) 75% N equivalent through compost and jeevamrutha at sowing (N_3), iv) 100% N equivalent through compost and jeevamrutha at sowing (N_4), v) 75% N equivalent through compost and jeevamrutha at sowing and 30 DAS (N_5), vi) 100% N equivalent through compost and jeevamrutha at sowing and 30 DAS (N_6). In each year, the field experiments were designed in factorial randomized-block design with three replicates. Jeevamrutha was prepared following the guidelines outlined by Palekar (2006) [23] and applied at a rate of 500 liters per hectare. Additionally, compost was applied at a rate of 8 tons per hectare, applied fifteen days prior to sowing the chia crop.

Observations recorded

Seed yield (kg/ha)

The plants were individually harvested from the designated plot area and subsequently sun-dried for a duration of 4-6 days in the threshing yard. Following threshing, the seeds were separated, cleaned, and weighed. Subsequently, the seed yield per net plot was calculated, converted to a per-hectare basis, and expressed in kilograms per hectare.

Net assimilation rate (g/cm²/day × 10⁻⁴)

Net assimilation rate (NAR) was calculated based on method given by Williams (1948) [34] and expressed as $g/cm^2/day \times 10^{-4}$.

$$NAR = \frac{(W_2 - W_1) \times (\text{Log}_e\, LA_2 - \text{Log}_e\, LA_1)}{(t_2 - t_1) \times (LA_2 - LA_1)}$$

Where,

W_1 and W_2 total dry weight of a plant at time t_1 and t_2, respectively. LA_1 and LA_2 are the leaf area at time t_1 and t_2, respectively.

Crop growth rate (g/cm²/day)

The calculation of crop growth rate follows the formula provided by Watson (1952) [33], expressing the rate as grams of dry matter produced per unit land area per day.

$$CGR = \frac{W_2 - W_1}{P(t_2 - t_1)}$$

Where, W_1 and W_2 are total dry weight of a plant at time t_1 and t_2, respectively. P is land area.

Specific leaf area (cm²/g)

The specific leaf area, proposed by Kvet *et al*. (1971) [17], quantifies the leaf area of the plant relative to its leaf dry weight, typically expressed in cm^2/g.

$$SLA = \frac{\text{Leaf area}}{\text{Leaf dry weight}}$$

Leaf production rate (leaf/day)

Leaf production rate can be calculated by the following formula.

$$LPR = \frac{Ln_2 - Ln_1}{t_2 - t_1}$$

Where, Ln_1 and Ln_2 are number of leaves at time t_1 and t_2, respectively.

Quality parameters

The crude protein content of the seed sample was determined using Bradford's method, a dye-binding technique, following the procedure outlined by Bradford (1976) [5]. The oil content (%) of the seed samples was assessed using the standard Soxhlet method, a procedure established by the IUPAC in 1992 [11]. Micronutrients such as zinc and iron in the seed samples were extracted through digestion with di-acid and quantified using Atomic Absorption Spectrophotometry, following the methodology described by Lindsay and Norvell (1978) [18].

Statistical analysis

Observations registered at various stages of the chia crop were subjected to statistical analysis. The analysis employed Fisher's method of analysis of variance (ANOVA), following the guidelines outlined by Gomez and Gomez (1984) [8]. The significance among the treatments was assessed using the 'F' test. Furthermore, the disparity between the means of treatments was examined through the critical difference (CD) test at a 5% level of significance.

Results and Discussion

Seed yield

Seed yield was notably affected by both row spacing and organic nutrient sources, as depicted in Table 1. However, the interaction effect was found to be non-significant concerning seed yield. A row spacing of 45 × 15 cm^2 resulted in a significantly higher seed yield of 843 kg/ha, while 60 × 15 cm^2 spacing achieved 752 kg/ha. Among the organic nutrient sources, the treatment receiving 100% N equivalent through compost and jeevamrutha at sowing and 30 DAS exhibited the highest seed yield of 972 kg/ha, which was statistically equivalent to the treatment receiving 100% N equivalent through compost and jeevamrutha at sowing (903 kg/ha). Conversely, a lower seed yield of 607 kg/ha was recorded for the treatment receiving 75% N equivalent through compost. This can be attributed to reduced competition among plants for space, light, soil moisture and nutrients, along with an increased accumulation of dry matter in reproductive parts (Kamble *et al*., 2022) [14]. Similar conclusions were drawn by Chaitanya *et al*. (2022) [6], who suggested that the higher yield may be due to a greater number of plants per unit area. Comparable findings were reported by Anbarasu *et al*. (2018) [2] in castor, Jingar *et al*. (2023) [13] in chia, Dubey *et al*. (2023) [7] in chia, and Rathod *et al*. (2024) [27] in chickpea. The enhanced yield with organic manures could be attributed to improvements in yield attributes. The combined application of Farm Yard Manure and vermicompost offers benefits to the crop throughout its growth period compared to the sole application of manures. The advantage of organic manure compost lies in its ability to supply nutrients in soluble form for an extended period, minimizing fixation and precipitation from the manures, thus allowing plant roots to compete effectively for nutrient absorption, resulting in improved yield (Kumar *et al*., 2017) [16].

Net assimilation rate

Table 1 presents the impact of various agronomic practices on the Net Assimilation Rate (NAR). There were no significant differences observed concerning row spacing, nutrient sources via organic manures, or their interaction. However, higher NAR values were recorded during 30 – 60 DAS with a spacing of 45 × 15 cm^2 (8.26 g/cm^2/day × 10^{-4}). Conversely, during 60 – 90 DAS, 45 × 15 cm^2 spacing exhibited higher values (7.13 g/cm^2/day × 10^{-4}). Numerically, a higher NAR (8.50 g/cm^2/day × 10^{-4} at 30 – 60 DAS) was obtained with 100% N equivalent through compost and jeevamrutha at sowing and 30 DAS, while 75% N equivalent through compost and jeevamrutha at sowing and 30 DAS recorded a higher NAR (7.46 g/cm^2/day × 10^{-4}) at 60 - 90 DAS. Lower NAR values were registered with 75% N equivalent through compost (7.88 and 6.27 g/cm^2/day × 10^{-4}, respectively, at 30 – 60 DAS and 60 - 90 DAS). NAR indirectly reflects the rate of net photosynthesis, representing the increase in plant dry weight per unit leaf area over a specific time period. It signifies a plant's ability to augment dry weight relative to its assimilatory surface area, thus indicating photosynthetic efficiency comprehensively. When analyzed alongside Leaf Area Ratio (LAR) and Relative Growth Rate (RGR), NAR helps assess plant growth responses to environmental conditions (Watson *et al*., 1947) [32]. Initially, NAR was high due to ample light penetration in the crop canopy and minimal shading and competition among plants for light and resources. However, it decreased considerably leading up to harvesting, possibly due to increased shading and competition among plants for resources. The rise in NAR with increasing plant population suggests enhanced photosynthetic activity. Similar findings have been reported by Sharifi and Pirzad (2011) [31] in maize hybrids and Moderras *et al*. (1998) [20], who indicated that increasing plant density enhances solar radiation capture within the canopy and boosts net assimilation rate. In our study, net assimilation rate per area increased with higher plant population.

Table 1: Net assimilation rate and seed yield as affected by different agronomic practices in chia\

Treatments	Net assimilation rate (g/cm^2/day × 10^{-4})						Seed yield (kg/ha)		
	30 – 60 DAS			60 – 90 DAS			At harvest		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Factor A: Row spacing (S)									
S_1	8.12	8.39	8.26	7.09	6.98	7.03	842	844	843
S_2	7.99	8.35	8.17	7.21	7.05	7.13	750	753	752
SE (m) ±	0.35	0.22	0.27	0.22	0.19	0.20	12	12	12
CD (P=0.05)	NS	NS	NS	NS	NS	NS	36	36	36
Factor B: Organic nutrient sources (N)									
N_1	7.92	7.85	7.88	6.26	6.27	6.27	606	608	607
N_2	8.03	8.06	8.04	7.04	7.03	7.03	756	758	757
N_3	8.00	8.39	8.19	7.10	6.93	7.01	702	704	703
N_4	8.02	8.44	8.23	7.40	7.22	7.31	902	904	903
N_5	8.28	8.57	8.43	7.50	7.42	7.46	842	845	844
N_6	8.08	8.91	8.50	7.61	7.20	7.41	971	974	972
SE (m) ±	0.60	0.38	0.46	0.38	0.32	0.34	21	21	21
CD (P=0.05)	NS	NS	NS	NS	NS	NS	63	62	62
Interaction (S × N)									
SE (m) ±	0.85	0.54	0.65	0.53	0.46	0.49	30	30	30
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Note: Treatment details are furnished in detail in Materials and Methods.

Crop growth rate

Crop growth rate (CGR) exhibited significant differences due to variations in row spacing and organic nutrient sources, while the interaction effect was found to be statistically non-significant. Row spacing of 45 × 15 cm^2 resulted in significantly higher CGR values (6.73, 14.28, and 26.58 g/cm^2/day, respectively, at 0 – 30, 30 – 60, and 60 – 90 DAS) compared to 45 × 15 cm^2 (5.48, 11.11, and 20.78 g/cm^2/day, respectively). Regarding nutrient sources via organic manures, the highest CGR values were significantly obtained with 100% N equivalent through compost and jeevamrutha at sowing and 30 DAS (7.44, 14.12, and 26.01 g/cm^2/day, respectively, at 0 – 30, 30 – 60, and 60 – 90 DAS), followed by 100% N equivalent through compost and jeevamrutha at sowing (6.79, 13.49, and 25.33 g/cm^2/day, respectively). CGR, as defined by Watson (1952) [33], represents the rate of crop growth per unit area per unit time. It shows an increase with higher levels of plant population within a given area. This rise in CGR with increased plant population could be attributed to accelerated photosynthesis activity and the favorable response of crop growth rate to plant density, findings corroborated by Jeffrey *et al*. (2005) [12]. Various factors, including temperature, solar radiation levels, water and nutrient availability, crop type, cultivar and age, impact crop growth rate by influencing the size and efficiency of the leaf canopy, thus affecting the crop's ability to convert solar energy into economic growth. In our study, we observed low crop growth rates at the outset, followed by substantial increases, consistent with findings by Sharifi and Pirzad (2011) [31]. Chaitanya *et al*. (2022) [6] similarly reported higher CGR with a spacing of 75 cm × 15 cm, attributing it to the increased plant population and higher dry matter production on a unit area basis in narrower spacing, resulting in greater light interception. Although individual plant canopy size increased with narrower spacing, overall CGR decreased due to lower plant population and dry matter production per unit area. These results align with the studies of Awais *et al*. (2013) [3] and Ramesh *et al*. (2017) [26]. The higher nutrient levels likely provided more nitrogen, stimulating vegetative growth and photosynthesis. Increased leaf area index may have enhanced light interception, further improving CGR, as suggested by Mondal *et al*. (2017) [21].

Table 2: Crop growth rate as affected by different agronomic practices in chia

Treatments	Crop growth rate (g/cm²/day)								
	0 - 30 DAS			30 – 60 DAS			60 – 90 DAS		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Factor A: Row spacing (S)									
S_1	6.70	6.77	6.73	14.03	14.53	14.28	26.78	26.371	26.58
S_2	5.43	5.52	5.48	10.85	11.36	11.11	21.03	20.531	20.78
SE (m) ±	0.25	0.12	0.17	0.55	0.30	0.40	0.73	0.625	0.67
CD (P=0.05)	0.74	0.35	0.50	1.61	0.87	1.16	2.14	1.832	1.95
Factor B: Organic nutrient sources (N)									
N_1	4.12	4.26	4.19	11.04	10.96	11.00	19.48	19.550	19.51
N_2	5.76	5.84	5.80	12.17	12.22	12.20	23.20	23.197	23.20
N_3	5.81	5.89	5.85	11.79	12.36	12.08	23.06	22.542	22.80
N_4	6.75	6.84	6.79	13.16	13.82	13.49	25.65	25.011	25.33
N_5	6.58	6.53	6.55	13.07	13.50	13.28	25.35	25.099	25.22
N_6	7.37	7.51	7.44	13.43	14.80	14.12	26.71	25.309	26.01
SE (m) ±	0.44	0.21	0.29	0.95	0.52	0.68	1.26	1.082	1.15
CD (P=0.05)	1.28	0.61	0.86	NS	1.51	2.01	3.70	3.174	3.38
Interaction (S × N)									
SE (m) ±	0.62	0.29	0.41	1.34	0.73	0.97	1.79	1.53	1.63
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Note: Treatment details are furnished in detail in Materials and Methods.

Specific leaf area

Upon reviewing the data presented in Table 3, it is evident that specific leaf area (SLA) did not exhibit significant variation concerning row spacing or the interaction between row spacing and organic nutrient sources at 30, 60 and 90 DAS. However, organic nutrient sources demonstrated a significant effect, except at 90 DAS. Row spacing of 45 × 15 cm² yielded statistically higher SLA values (59.02, 50.76 and 54.25 cm²/g, respectively at 30, 60 and 90 DAS), while a lower value (56.96, 48.00 and 53.10 cm²/g, respectively) was observed with 60 × 15 cm² spacing. Regarding organic nutrient sources, 75% N equivalent through compost recorded the maximum SLA values (69.47, 59.29 and 60.65 cm²/g, respectively at 30, 60 and 90 DAS), while the minimum SLA values (51.41, 43.13 and 49.58 cm²/g, respectively) were registered with 100% N equivalent through compost and jeevamrutha at sowing and 30 DAS. Specific leaf area (SLA) serves as an indicator of the "leafiness of the leaf" and represents the ratio between total leaf area per plant and total leaf weight per plant, as proposed by Kvet *et al*. (1971) [17]. These results are in conformity with Rouiss *et al*. (2019) [28].

Leaf production rate

Row spacing and organic nutrient sources exhibited a significant influence on leaf production rate (LPR) at 0 - 30 DAS, while at 30 – 60 DAS and 60 – 90 DAS, their effect was non-significant (Table 4). Specifically, the row spacing of 60 × 15 cm² demonstrated an enhanced LPR, yielding 1.2206, 2.5946 and 1.9364 leaf/day, respectively at 0 - 30 DAS, 30 – 60 DAS and 60 – 90 DAS. Application of 100% N equivalent through compost and jeevamrutha at sowing and 30 DAS resulted in higher LPR values of 1.3911 leaf/day at 0 - 30 DAS, 2.7477 leaf/day at 30 – 60 DAS and 2.2612 leaf/day at 60 – 90 DAS. Conversely, lower LPR values of 0.9012 leaf/day at 0 - 30 DAS, 2.2564 leaf/day at 30 - 60 DAS and 1.4820 leaf/day at 60 – 90 DAS were obtained with 75% N equivalent through compost. The results suggest that LPR initially increased up to 60 DAS and then gradually decreased.

Quality parameters

Table 5 presents the aggregated data regarding crude protein, oil, zinc and iron content influenced by both spacing and organic nutrient sources. No significant variations were observed among row spacing or their interaction concerning quality parameters. However, the impact of various nutrient sources via organic manures on the quality parameters of the chia crop was found to be significant. Application of 100% RDN equivalent compost and jeevamrutha at sowing and 30 DAS resulted in significantly higher crude protein, oil, zinc and iron content, with values of 23.42%, 31.47%, 3.94 mg/100 g, and 6.97 mg/100 g, respectively.

Table 3: Specific leaf area as affected by different agronomic practices in chia

Treatments	Specific leaf area (cm^2/g)								
	30 DAS			60 DAS			90 DAS		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Factor A: Row spacing (S)									
S_1	59.58	58.48	59.02	50.95	50.58	50.76	54.35	54.14	54.25
S_2	57.50	56.43	56.96	48.14	47.85	48.00	53.18	53.01	53.10
SE (m) ±	1.93	1.87	1.90	1.56	1.54	1.55	2.10	2.09	2.10
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Factor B: Organic nutrient sources (N)									
N_1	70.26	68.71	69.47	59.55	59.05	59.29	60.81	60.49	60.65
N_2	58.71	57.66	58.18	51.61	51.31	51.46	53.76	53.58	53.67
N_3	58.17	57.07	57.61	49.53	49.19	49.36	55.17	54.97	55.07
N_4	59.27	58.16	58.71	47.72	47.43	47.57	53.55	53.39	53.47
N_5	53.10	52.06	52.57	45.63	45.30	45.46	49.67	49.53	49.60
N_6	51.73	51.09	51.41	43.24	43.01	43.13	49.64	49.51	49.58
SE (m) ±	3.34	3.24	3.29	2.70	2.66	2.68	3.65	3.62	3.63
CD (P=0.05)	9.79	9.51	9.65	7.91	7.80	7.85	NS	NS	NS
Interaction (S × N)									
SE (m) ±	4.72	4.59	4.65	3.81	3.76	3.79	5.15	5.12	5.14
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Note: Treatment details are furnished in detail in Materials and Methods.

Table 4: Leaf production rate as affected by different agronomic practices in chia

Treatments	Leaf production rate (leaf/day)								
	0 - 30 DAS			30 – 60 DAS			60 – 90 DAS		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Factor A: Row spacing (S)									
S_1	1.0961	1.1014	1.0988	2.4370	2.4364	2.4367	1.7879	1.7876	1.7878
S_2	1.2178	1.2234	1.2206	2.5955	2.5937	2.5946	1.9362	1.9365	1.9364
SE (m) ±	0.0299	0.0298	0.0299	0.0989	0.0987	0.0988	0.1449	0.1447	0.1448
CD (P=0.05)	0.0878	0.0875	0.0876	NS	NS	NS	NS	NS	NS
Factor B: Organic nutrient sources (N)									
N_1	0.8974	0.9050	0.9012	2.2578	2.2549	2.2564	1.4816	1.4823	1.4820
N_2	1.1313	1.1366	1.1340	2.4250	2.4239	2.4245	1.7793	1.7791	1.7792
N_3	1.0528	1.0575	1.0552	2.3393	2.3393	2.3393	1.5914	1.5908	1.5911
N_4	1.3031	1.3086	1.3058	2.7123	2.7103	2.7113	2.1009	2.1014	2.1012
N_5	1.1688	1.1731	1.1709	2.6148	2.6148	2.6148	1.9581	1.9574	1.9578
N_6	1.3883	1.3938	1.3911	2.7483	2.7471	2.7477	2.2610	2.2614	2.2612
SE (m) ±	0.0518	0.0517	0.0518	0.1712	0.1709	0.1711	0.2509	0.2507	0.2508
CD (P=0.05)	0.1520	0.1515	0.1518	NS	NS	NS	NS	NS	NS
Interaction (S × N)									
SE (m) ±	0.0733	0.0731	0.0732	0.2422	0.2417	0.2419	0.3549	0.3546	0.3547
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS

Note: Treatment details are furnished in detail in Materials and Methods.

Table 5: Quality parameters as affected by different agronomic practices in chia

Treatments	Crude protein content (%)			Oil content (%)			Zinc content (mg 100 g^{-1})			Iron content (mg 100 g^{-1})		
	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled	2020	2021	Pooled
Factor A: Row spacing (S)												
S_1	22.58	22.67	22.62	29.98	30.06	30.02	3.61	3.68	3.65	6.25	6.30	6.27
S_2	22.06	22.15	22.10	29.04	29.15	29.09	3.34	3.44	3.39	5.77	5.81	5.79
SE (m) ±	0.18	0.18	0.18	0.47	0.47	0.47	0.14	0.14	0.14	0.21	0.21	0.21
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Factor B: Organic nutrient sources (N)												
N_1	20.48	20.56	20.52	27.12	27.21	27.16	2.79	2.86	2.83	4.96	5.03	5.00
N_2	22.33	22.47	22.40	29.29	29.38	29.33	3.44	3.55	3.49	5.76	5.80	5.78
N_3	22.16	22.25	22.21	28.55	28.64	28.60	3.26	3.35	3.30	5.47	5.50	5.48
N_4	22.94	23.01	22.97	30.74	30.87	30.81	3.81	3.86	3.84	6.66	6.69	6.67
N_5	22.62	22.71	22.66	29.95	29.99	29.97	3.67	3.76	3.71	6.26	6.31	6.29
N_6	23.40	23.45	23.42	31.41	31.53	31.47	3.90	3.97	3.94	6.95	6.99	6.97
SE (m) ±	0.32	0.31	0.31	0.82	0.81	0.81	0.24	0.25	0.24	0.37	0.36	0.37
CD (P=0.05)	0.93	0.90	0.91	2.40	2.37	2.39	0.71	0.72	0.72	1.08	1.07	1.08
Interaction (S × N)												
SE (m) ±	0.45	0.43	0.44	1.16	1.14	1.15	0.34	0.35	0.35	0.52	0.52	0.52
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

Note: Treatment details are furnished in detail in Materials and Methods.

Conversely, lower values were recorded with the application of 75% RDN equivalent compost, with values of 20.52%, 27.16%, 2.83 mg/100 g, and 5.00 mg/100 g, respectively. The rise in crude protein content may be attributed to the increased nitrogen content in the seeds. These findings are consistent with previous studies by Mary *et al*. (2018) [19] and Grimes *et al*. (2019) [9]. They corroborate earlier research on various crops, such as the observations made by Hocking and Mason (1993) [10], Mumtaz Akhtar *et al*. (2001) [22] and Akbari *et al*. (2011) [1], who noted that higher nitrogen application resulted in elevated protein content in seeds. Additionally, the results align with findings from Saleem *et al*. (2001) [29], indicating that oil content decreases with increasing nitrogen levels. Akbari *et al*. (2011) [1] observed in sunflower that higher nitrogen rates stimulate amino acid synthesis in leaves, leading to increased protein accumulation in seeds at the expense of oil content. Moreover, the presence of nitrogen compounds in seed oil complicates the oil extraction process and elevates the amount of undesirable materials, as noted by Zangani (2002) [35].

Conclusion

Based on the above findings, it is evident that both row spacing and organic nutrient sources have the potential to impact the yield and crop growth indices of chia crops. Consequently, it can be inferred that row spacing significantly influenced CGR and seed yield, while showing no significant difference concerning NAR, SLA, LPR (except at 0 – 30 DAS) and quality parameters. Similarly, organic nutrient sources significantly influenced CGR, SLA (except at 90 DAS) and quality parameters. A row spacing of 45 × 15 cm^2 resulted in higher seed yield, NAR, CGR, SLA and quality parameters, while 60 × 15 cm^2 exhibited a higher LPR. Moreover, the application of 100% N equivalent through compost and jeevamrutha at sowing and 30 DAS yielded superior seed yield, NAR, CGR, LPR and quality parameters. Conversely, 75% N equivalent through compost led to higher SLA.

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