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Crop Growth,Yield Attributes,Yield and Quality of Chia (*Salvia hispanica* L.) as Influenced by Spacing and Fertilizer Levels

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A field experiment was conducted during *Kharif* season-2019 at Agricultural Research Station, Chintamani, Karnataka. The experiment consisted of four levels of spacing (45 × 15, 45 × 30, 60 × 15, and 60 × 30 cm) and three levels of fertilizer (40:20:20, 60:40:40 and 80:60:60 kg NPK ha^{-1}). The experiment was arranged in a statistical design of Factorial Randomized Complete Block Design (FRCBD) with three replications to determine the influence of different spacing and fertilizer

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levels on growth, yield and quality of chia (*Salvia hispanica* L). The report of the study indicated that the wider spacing of 60 × 30 cm produced a significantly higher number of primary branches per plant (22.38), secondary branches plant^{-1} (27.69), Dry matter accumulation plant^{-1} (146.09 g) and leaf area plant^{-1} (4292 cm^2), number of spikes plant^{-1} (81.68), number of spikelets spike^{-1} (28.50), spike length (14.82 cm), seed weight spike^{-1} (0.23 g), seed yield plant^{-1} (18.62 g), seed yield (1015.92 kg ha^{-1}), haulm yield (4765.26 kg ha^{-1}), protein (22.93%) and oil content (29.44%) as compared to 45 × 30, 45 × 15 cm and 60 × 15 cm spacing's. However, lower spacing of 45 × 15 cm registered significantly higher plant height (125.57 cm), leaf area index (7.19 at 90 DAS), crop growth rate and relative growth rate over other levels. Among the fertilizer levels, application of 80:60:60 kg NPK ha^{-1} noticed significantly higher plant height (125.59 cm), primary branches (22.47), secondary branches(27.63), dry matter accumulation (131.47 g) and leaf area plant^{-1} (4556 cm^2), number of spikes plant^{-1} (72.26), seed yield plant^{-1} (12.65 g), seed yield ha^{-1} (1020.53 kg ha^{-1}), haulm yield (4124.91 kg ha^{-1}) at harvest and also observed faster Crop Growth Rate, Relative Growth Rate and Leaf Area Index over other fertilizer level of 60:40:40 kg NPK ha^{-1} and 40:20:20 kg NPK ha^{-1} at all the growth stages of the crop but oil content and omega -3-fatty acid(Alpha-linolenic acid) content was obtained at lower fertilizer level of 40:20:20 NPK kg ha^{-1} (30.96% and 55.65% respectively) and higher level of fertilizer 80:60:60 NPK kg ha^{-1} recorded maximum protein content (22.67%). Significantly higher seed yield (1122 kg ha^{-1}) was obtained in the treatment combination of 60 × 30 cm with 80:60:60 kg NPK ha^{-1} compared to other treatments.

Keywords: Chia; fertilizer; spacing; growth parameters; yield and quality parameters.

1. INTRODUCTION

India is likely to be the most populous country on this planet by 2030 with 1.6 billion people. It currently accounts for more than 17% of the global population and 456 million poor, or 41.6% living on less than $1.25 a day [1]. Ensuring food and nutrition security is thus a challenge for India. Despite historically high levels of food production in India, undernourishment problem persist. At present, 22.5 percent of adults are underweight, and 38 percent are still stunted [2]. Current high levels of malnutrition are often due to unbalanced diets with insufficient nutrition diversity. Indian diets reliance primarily on traditional staple crops for energy. Even if traditional staple crops provide enough calories to prevent hunger, they do not provide all the nutrients necessary for a healthy diet. Improving the health of the people requires improving their nutrition through better and more nutritious food. Now –a –days, consumer's tendency for choosing food crops like chia, nutrimillets, grain amaranth are more associated with multiple health benefits and wellness.

Chia (*Salvia hispanica* L.) is an annual oilseed crop belonging to the family of Lamiaceae originated in Mexico and Guatemala [3]. As Chia a super food crop known for its high nutritional value, has gained attention as a potential solution to combat malnutrition. Chia seeds are packed with essential nutrients, including omega-3 & 6 fatty acids , dietary fibre (25%), proteins (20%), oil (35%), minerals ,vitamins and great source of antioxidants and amino acids particularly lysine, which are essential for normal human growth and development and further appears to be important for the prevention and treatment of several non-infectious diseases such as obesity, hypertension, cardiovascular diseases (CVDs), cancer and diabetes. Nutritional and therapeutic aspects of chia are currently being researched by many scientific centres. It has a major role to play in human nutrition and health.

The cultivation of Chia (*Salvia hispanica* L.) is gaining popularity in world due to its health benefits hence, chia is recognised as super food crop for its superior nutritional value. It is consumed as seeds and can be used as food supplements [4]. Commercial cultivation of Chia is gaining momentum all over the world, but in India it is in budding stage. In recent years cultivation of this crop was started in Karnataka by the farmers of Mysore and chamarajanagara districts under the technical guidance of Central Food Technological Research Institute (CFTRI), Mysore about its nutritional quality.

Effective agronomic management stands as a pivotal factor in cultivation of any crop, driven by the proficient utilization of all available resources. Cultural practices such as crop arrangement, irrigation, weed control, and nutritional strategies are principal influencers of crop productivity. With chia being a novel addition to India's agricultural landscape, particularly within Karnataka, comprehending its growth patterns and reactions to inputs becomes paramount for optimizing profits from its cultivation. A comprehensive exploration of diverse facets encompassing plant population, spatial distribution, and nutrient demands is imperative to unlock its full yield potential. The establishment of context-specific agronomic protocols, encompassing suitable spacing and precise fertilizer application, emerges as a requisite for fostering the widespread adoption of this crop within the Eastern dry zone of Karnataka.

2. MATERIALS AND METHODS

The field study was carried out in the *Kharif* season of 2019 at Agricultural research Station, Chintamani, Karnataka, situated at 13° 24' N Latitude and 78° 04' E Longitude at elevation of 918 m above Mean Sea Level (MSL) in Eastern Dry Zone of Karnataka (EDZ). During the crop growing period (July 2019 – November 2019), the actual total rainfall recorded was 497.50 mm, which was higher than the normal rainfall of 394.5 mm. The mean maximum temperature fluctuated between 29.0 °C and 30.9 °C, while the minimum temperature ranged from 18.9 °C to 20.9 °C. In terms of relative humidity, the highest value of 82 % was recorded in November. Composite soil samples were taken at random from top 15 cm layer in the experimental area and were analyzed for the soil physic-chemical properties by using different standard methods revealed that the soil was sandy loam in texture with a water holding capacity of 38.60 percent, the pH of the soil is acidic (5.60) and electrical conductivity was normal (0.16 dS m^{-1} at 25°C). The soil was medium in organic carbon content (0.54%), medium in available nitrogen (366.91 kg ha^{-1}), phosphorus (46.69 kg ha^{-1}) and high in potassium (373.10 kg ha^{-1}). Experiment was laid out in Factorial Randomized Complete Block Design (FRCBD) having four spacing levels (45×15, 45×30, 60×15 and 60×30 cm) and three levels of fertilizers (40:20:20, 60:40:40, and 80:60:60 kg NPK ha_{-1}) with twelve treatments combinations. The details of treatment are T_1 – S_1F_1: 45 × 15 cm + 40:20:20 kg NPK ha^{-1} ; T_2 – S_1F_2: 45 × 15 cm + 60:40:40 kg NPK ha^{-1} ; T_3 – S_1F_3: 45 × 15 cm + 80:60:60 kg NPK ha^{-1} ; T_4 – S_2F_1: 45 × 30 cm + 40:20:20 kg NPK ha^{-1} ; T_5 – S_2F_2: 45 × 30 cm + 60:40:40 kg NPK ha^{-1} ; T_6 – S_2F_3: 45 × 30 cm + 80:60:60 kg NPK ha^{-1} ; T_7 – S_3F_1: 60 × 15 cm + 40:20:20 kg NPK ha^{-1} ; T_8 – S_3F_2: 60 × 15 cm + 60:40:40 kg NPK ha^{-1} ; T_9 – S_3F_3: 60 × 15 cm + 80:60:60 kg NPK ha^{-1} ; T_{10} – S_4F_1: 60 × 30 cm + 40:20:20 kg NPK ha^{-1} ; T_{11} – S_4F_2: 60 × 30 cm + 60:40:40 kg NPK ha^{-1} ; T_{12} – S_4F_3: 60 × 30 cm + 80:60:60 kg NPK ha^{-1} replicated thrice. with a plot size of 19.44 m^2 (5.4 m × 3.6 m) each. Crop variety 'CHIAmpion B-1' seeds were collected from Central Food Technological Research Institute (CFTRI), Mysore, and seeded manually on the fourth week of June and harvested on the first week of November. The crop geometry was maintained as per the spacing prescribed for the treatments. Nitrogen, phosphorus, and potassium were provided through Urea, Single super phosphate (SSP), and Muriate of Potash (MOP) according to treatments. A full dose of phosphorus, potassium, and half dose of nitrogen was applied as basal during sowing while, the remaining half of nitrogen was top dressed at 40 days after sowing (DAS). Five plants were selected at random and labelled in each net plot for recording non-destructive observations on growth and yield parameters. The observations on growth parameters viz. plant height, number of primary and secondary branches, leaf area and dry weight were taken at 30, 60, 90 DAS, and at harvest, Leaf area per plant was worked out by using leaf area meter (INC/LI-COR Ltd., Nebraska, USA) and expressed as cm^2 $plant^{-1}$. Leaf area index and crop growth rate was computed by using formula [5].

$$\text{Leaf area index} = \frac{\text{Leaf area plant}^{-1}\ (cm^2)}{\text{Ground area plant}^{-1}\ (cm^2)}$$

$$\text{CGR} = \frac{W_2 - W_1}{t_2 - t_1} \times \frac{1}{P}$$

Where, W_1 and W_2 = Dry matter production $plant^{-1}$ in g at time t_1 and t_2, respectively. P = Spacing (m^2) and it is expressed in g m^{-2} day^{-1}. Relative growth rate was calculated as suggested by Radford [6].

$$\text{RGR} = \frac{\log_e W_2 - \log_e W_1}{t_2 - t_1}$$

Where, W_1 and W_2 are dry weights of plant at time $t_1$and t_2, respectively,

The number of days taken to 50 per cent flower production was recorded by counting the days from sowing to the date at which the plants produced 50 per cent of flowers in each treatment and expressed in days. Number of days taken for maturity was recorded in each treatment by considering the indications such as drying of the leaves, spike turning into brown colour and hardening of seeds and the data on yield characters viz. The number of spikes per plant, seed yield per plant, test weight and seed and haulm yield were recorded at harvest. The quality parameters like oil, protein and fatty acid composition (α- linolenic acid, linoleic acid, oleic acid, palmitic acid and stearic acid) were determined by AOAC approved methods. Oil content in seeds is estimated by Soxhlet method. IUPAC standard method, [7], FLASH 2000 N/protein Analyzer is used for the estimation of protein content, based on modified Dumas method or Dynamic Flash Combustion technique. Fatty acid was determined by Gas Chromatography Mass spectrometer (GCMS) method [8] using the instrument Agilent 7890B GC, 5977AMSD. Fatty acid methyl esters (FAME) were prepared as described by Maia and Rodriguez- Amaya [9]. Experimental data collected was statistically analysed by adopting Fisher's method of Analysis of Variance (ANOVA) as suggested by Gomez and Gomez [10]. Whenever the 'F' test was found significant at 5 per cent level Critical Difference (CD) values were calculated.

3. RESULTS AND DISCUSSION

3.1 Effect of Spacing and Fertilizer Levels on Growth of Chia Crop

The data on growth parameters at harvest as influenced by spacing and fertilizer levels are presented in Tables 1 to 3. Spacing plays an important role in crop production as non-monetary input. Closer spacing of 45 × 15 cm was attained significantly higher plant height (125.57 cm), which was on par with a spacing of 60 × 15 cm but statistically, superior over other spacing of 45 × 30 and 60 × 30 cm (Table 1) . This was apparently because individual plants with narrow spacing did not get the opportunity to proliferate laterally due to the less lateral space. Hence plants were compelled to grow more in an upward direction for the fulfilment of the light requirement for photosynthesis. Significant increase in plant height from early stages of crop growth under closer spacing (45 × 15 cm) might be due to mutual shading because of the dense population which might have decreased the availability of light to the plants. These results are in close agreement with the findings of Singh et al. [11] in basil, Yeboah et al. [12], Bilalis et al. [13], Mary et al. [14] and Nunavath at al. [2] in chia and Pooja et al. [15] in sacred basil.

The wider spacing of 60 × 30 cm produced a significantly higher number of primary branches per plant (22.38), secondary branches per plant (27.69), Dry matter accumulation per plant (146.09 g) and leaf area per plant (4292 cm^2) as compared to 45 × 30, 45 × 15 cm and 60 × 15 cm spacing's. While the number of secondary branches was on par with 45 × 30 cm spacing at the harvest stage. Plants at wider spacing received higher growth inputs (sunlight, water, and nutrient) and availability of more space for spreading of branches which helped in more interception of light due to higher leaf surface area with lesser competition as compared to plants grown under closer spacing. This resulted in an increased number of primary and secondary branches, this, in turn, resulted in the production of more leaves per plant and total dry matter accumulation per plant due to more inter-row intra-row row spacing (60 × 30 cm). The results were in agreement with the findings of Kailash and kushwaha [16] in basil, Yeboah et al. [12] in chia, Mahantesh et al. [17] in Japanese mint, and Mary et al. [14] in chia.

Among the fertilizer levels, application of 80:60:60 kg NPK ha^{-1} noticed significantly higher plant height (125.59 cm), primary branches (22.47), secondary branches(27.63) , dry matter accumulation (131.47 g) and leaf area per plant (4556 cm^2) at harvest compared to other fertilizer levels i.e., 60:40:40 kg NPK ha^{-1} and 40:20:20 kg NPK ha $^{-1}$ (Table 1). The increased growth components might be due to nitrogen which triggers the growth of meristematic tissue and efficient utilization of resources by the plants manifested in the production of taller plants. Split application of nitrogen at higher dosage might have contributed production of more branches per plant particularly secondary branches due to the availability of nitrogen in optimum quantities. The outcomes of these studies agreed with the findings of Singh et al. [11] in french basil, Coates et al. [18], Kailash and kushwaha [16] in basil, Mahantesh et al. [17] in mint, Mary et al. [14] in chia, Pooja et al. [15] in sacred basil and Salman et al. [19] in chia. Treatment combinations of spacing and fertilizer levels did not attain the level of significance with respect to plant height, primary and secondary branches, and dry matter accumulation per plant at all the growth durations and leaf area per plant at harvest.

Closer spacing of 45 × 15 cm registered significantly faster crop growth rate as compared to other spacing of 60 × 15 cm, 45 × 30 cm and

60 × 30 cm at 0- 30 and 30- 60 DAS. However, at 60-90 DAS spacing of 60 × 15 cm recorded significantly higher crop growth rate as compared to 45 × 30 cm and 60 × 30 cm but 60 × 15 cm spacing was found statistically on par with 45 × 15 cm spacing. With respect to relative growth rate during crop growth stages of 0-30 and 60-90 DAS spacing of 60 × 30 cm registered significantly higher relative growth rate as compared to 45 × 15 cm and 60 × 15 cm but it was found statistically on par with 45 × 30 cm spacing. However, wider spacing of 60 × 30 cm noted significantly higher relative growth rate as compared to other spacing of 45 × 30 cm 60 × 15 cm and 45 × 15 cm at 30-60 DAS (Table 2).

Faster crop growth rate and relative growth rate was noticed with the application of higher dose of fertilizer of 80:60:60 kg NPK ha^{-1} which was significantly superior over other fertilizer dosage of 60:40:40 kg NPK ha^{-1} and 40:20:20 kg NPK ha^{-1} at 30-60 and 60-90 DAS. However it was found statistically on par with 60:40:40 kg NPK ha^{-1} at 0-30 DAS with respect crop growth rate and relative growth rate (Table 2). Significantly faster crop growth rate was recorded with combination of 60 × 15 cm spacing along with 80:60:60 kg NPK ha^{-1}fertilizer application followed by 45 × 15 cm spacing with fertilizer level of 80:60:60 kg NPK ha^{-1} which were on par with each other but significantly superior over other treatment combinations. However, during 0-30 and 30-60 DAS interaction of spacing and fertilizer levels did not influence crop growth rate and relative growth rate up to the level of significance at all the growth stages.

Crop growth rate recorded higher for closely spaced plants between 0-30, 30-60 and 60-90 DAS respectively as compared to wider spaced plants. This was due to less land area available for individual plant under high plant density. Hence, per unit area, plants produce more growth rate over time. The growth rate of crops also increased with an increase in fertilizer content. The rate of growth of individual plant increased with time due to the increased dose of fertilizer level that may be attributed to increase maximum deposition of dry matter $plant^{-1}$*i.e.* increased number of branches, leaves, spikes and leaf area. RGR and NAR also influenced by different spacing and fertilizer application. Similar results were reported by Mary et al. [14], Jaybhay et al. [20].

Spacing of 45 × 15 cm produced significantly higher of leaf area index as compared to 60 × 15 cm, 45 × 30 and 60 × 30 cm spacing at 30, 60, 90 DAS and at harvest (Table 3). The decrease in Leaf Area Index (LAI) at wider spacing was connected to higher land area engaged by each plant. On the conflicting, increase in spacing significantly improved the photosynthesizing surface area. This result was supported by the findings of Bilalis et al. [13] in chia who reported higher leaf area index at closer spacing compared to a wider spacing. These result were supported by Mary et al. [14] in chia. Among fertilizer applications higher fertilizer dose of 80:60:60 NPK kg $ha^{-1}$was recorded significantly higher Leaf Area Index over other fertilizer level of 60:40:40 kg NPK ha^{-1} and 40:20:20 kg NPK ha^{-1} at all the growth stages of the crop. These might be attributed to the production of a greater number of twigs and leaves which may be due to uptake of more nitrogen, phosphorus and potassium and effective production of photosynthates and its utilization. These results are line with findings of Montemurro and de Giorgio [21], Coates [18] and Mary et al. [14] in chia. The interaction effect of 45 × 15 cm spacing along with application of 80:60:60 kg NPK ha^{-1} was significantly superior than all other treatment combinations with respect to leaf area index at 90 DAS and at harvest only.

It was evident from the data presented in Table 4 that the different spacing and fertilizer levels and its interaction did not influence Days to 50 per cent flowering and physiological maturity and its interaction. Though, wider spacing of 60× 30 cm and application of higher dose of fertilizer at 80:60:60 kg NPK ha^{-1} had taken more number of days to 50 per cent flowering and physiological maturity as compared to the other spacing and fertilizer levels. However, closer spacing induced early flowering and physiological maturity of chia. This may be due to competition between plants for resources under closer spacing might have created stressed condition, which might have induced early flowering and physiological maturity of chia. Higher dose of nutrients particularly nitrogen enhanced vegetative growth like branches and canopy spread this lead to little delay in attaining of 50 per cent flowering and physiological maturity with higher dose of fertilizer application. These results are finding with the lines of Mary et al. [14] in Chia.

Table 1. Influence of spacing and fertilizer levels on growth parameters of chia at harvest

Treatments	Plant Height (cm)	Number of branches per plant		Dry matter accumulation per plant (g)	Leaf Area (cm^2)
		Primary branches	Secondary branches		
Spacing (S)					
S_1: 45 × 15 cm	125.57	20.76	23.69	86.07	3639
S_2: 45 × 30 cm	112.96	21.60	26.80	131.25	3926
S_3: 60 × 15 cm	118.60	21.02	25.59	116.55	3762
S_4: 60 × 30 cm	108.93	22.38	27.69	146.09	4292
S.Em±	2.70	0.27	0.55	2.70	112.75
CD (P=0.05)	7.92	0.78	1.61	7.91	330.68
Fertilizer levels (F)					
F_1: 40:20:20 kg NPK ha^{-1}	108.35	20.35	24.22	107.36	3122
F_2: 60:40:40 kg NPK ha^{-1}	115.60	21.50	25.98	121.14	4035
F_3: 80:60:60 kg NPK ha^{-1}	125.59	22.47	27.63	131.47	4556
S.Em±	2.33	0.23	0.48	2.34	97.64
CD (P=0.05)	6.86	0.68	1.39	6.85	286.38
Interaction (S×F)					
S.Em±	4.67	0.46	0.95	5.49	195.29
CD (P=0.05)	NS	NS	NS	NS	NS

Table 2. Influence of spacing and fertilizer levels on crop growth rate (g m^{-2} day^{-1}) and relative growth rate (g g^{-1} day^{-1}) per plant at different growth stages of chia

Treatments	Crop Growth Rate (g m^{-2} day^{-1})			Relative Growth Rate (g g^{-1} day^{-1})		
Treatments	0-30 DAS	30-60 DAS	60- 90 DAS	0-30 DAS	30-60 DAS	60- 90 DAS
Spacing (S)						
S_1: 45 × 15 cm	6.23	21.65	20.94	0.0869	0.0478	0.0183
S_2: 45 × 30 cm	3.71	15.37	17.07	0.0924	0.0528	0.0210
S_3: 60 × 15 cm	5.19	20.13	22.43	0.0902	0.0509	0.0208
S_4: 60× 30 cm	2.90	12.78	14.36	0.0937	0.0547	0.0215
S.Em±	0.12	0.41	0.51	0.0008	0.0006	0.0004
CD (P=0.05)	0.36	1.21	1.50	0.0023	0.0016	0.0012
Fertilizer levels (F)						
F_1: 40:20:20 kg NPK ha^{-1}	4.22	15.46	14.69	0.0889	0.0500	0.0187
F_2: 60:40:40 kg NPK ha^{-1}	4.54	17.48	18.70	0.0910	0.0515	0.0206
F_3: 80:60:60 kg NPK ha^{-1}	4.76	19.51	22.71	0.0925	0.0531	0.0220
S.Em±	0.11	0.36	0.44	0.0007	0.0005	0.0003
CD (P=0.05)	0.31	1.04	1.30	0.0020	0.0014	0.0010
Interaction (S×F)						
S.Em±	0.21	0.71	0.88	0.0013	0.0010	0.0007
CD (P=0.05)	NS	NS	2.59	NS	NS	NS

Table 3. Influence of spacing and fertilizer levels on leaf area index per plant at different growth stages of Chia

Treatments	30 DAS	60 DAS	90 DAS	At harvest
Spacing (S)				
S_1: 45 × 15 cm	2.09	3.59	7.19	5.39
S_2: 45 × 30 cm	1.14	1.94	3.88	2.91
S_3: 60 × 15 cm	1.68	2.79	5.45	4.18
S_4: 60× 30 cm	0.89	1.76	3.41	2.38
S.Em±	0.03	0.89	0.16	0.11
CD (P=0.05)	0.09	0.25	0.47	0.34
Fertilizer levels (F)				
F_1: 40:20:20 kg NPK ha^{-1}	1.26	1.94	3.88	2.91
F_2: 60:40:40 kg NPK ha^{-1}	1.49	2.61	5.24	3.86
F_3: 80:60:60 kg NPK ha^{-1}	1.60	3.01	5.83	4.38
S.Em±	0.02	0.07	0.14	0.10
CD (P=0.05)	0.08	0.22	0.40	0.30
Interaction (S×F)				
S.Em±	0.05	0.15	0.27	0.20
CD (P=0.05)	NS	NS	0.81	0.60

3.2 Effect of Spacing and Fertilizer Levels on Yield and Yield Parameters of Chia

The perusal data on yield attributes presented in Table 4 indicated that chia sown at a wider spacing of 60 × 30 cm has produced significantly more spikes per plant and seed yield per plant than other spacing levels of 45 × 30 cm, 60 × 15 cm and 45 × 15 cm. Among the fertilizer, dosage of 80:60:60 kg NPK ha^{-1} has produced a significantly greater number of spikes per plant and seed yield per plant which were statistically superior over 60:40:40 kg NPK ha^{-1} and 40:20:20 kg NPK ha^{-1}. However, spacing, fertilizer levels, and their interaction failed to register a significant difference in test weight (1000 seed weight) though the maximum test weight was recorded when the crop was maintained at wider spacing at 60 × 30 cm. The treatment combination of wider spacing of 60 × 30 cm and application of a higher dose of 80:60:60 kg NPK ha^{-1} produced a significantly higher number of spikes per plant and seed yield per plant as compared to other levels. This yield attributing characters may be attributed to greater inputs resulted in profused branching which in turn production of higher number of spike per plant and also ascribed to the increased branching and translocation of photosynthates to reproductive parts. The results are agreeing with the findings of Mary et al. [14] in chia and Jaybhay [20] in soybean. Production of seed yield per plant due to better interaction of nitrogen, phosphorus and potassium at higher levels. These results are confirmed with the findings of Malik et al. [22], Kwizera et al. [23] in sunflower.

The seed and haulm yield (Table 4) were influenced significantly due to varying spacings. The percent increase in seed yield of chia due to wider spacing of 60 × 30 cm was 24.69, 10.92, and 43.97 moreover of 60 × 15 cm, 45 × 30 cm, and 45 × 15 cm spacing, respectively, In percentage of haulm yield of chia due to wider spacing of 60 × 30 cm was 37.83, 15.09, and 59.58 percent more over of 60 × 15 cm, 45 × 30 cm and 45 × 15 cm spacing's, respectively. Higher seed yield achieved from the wider spacing of 60 × 30 cm might be due to a number of spikes and spikelets per plant, spike length, and seed yield per plant and the haulm yield were probably due to significant improvement in the parameters like a number of branches and leaves per plant, dry matter accumulation than the narrow spacing of 60 × 15 cm, 45 × 30 cm and 45 × 15 cm. Yeboah et al. [12] also reported significantly higher seed yield with wider spacing of 50 × 50 cm and 60 × 45 cm spacing, respectively. These results are in accordance with the findings of Mary et al. [14] who found the adaption wider spacing increased the productivity of chia crop. Seed and haulm yield of chia crops significantly increased with an increase in fertilizer levels. The highest fertilizer level F_1 (80:60:60 kg NPK ha^{-1}) gave the highest seed yield at the rate of 43.86 percent as compared to the lower fertilizer level (F3) and 19.01 percent higher as compared to the moderate level (F2).

This was attributed to increased fertilizer application which led to nutrient uptake by plants and increased synthesis of photosynthates and better translocation of nutrients. The higher yield levels associated with the application of higher levels of fertilizers were related to higher yield attributes such as a number of spikes, longer spikes, a higher number of spikelets per plant, and seed weight per plant. These results are in accordance with the findings of Mary et al. [14] who found the application of fertilizers as high as 90:60:75 kg NPK ha^{-1} increased the productivity of Chia.

Haulm yield was significantly lower at lower fertilizer levels (F_1 and F_2) which was reduced at the rate of 14.11 per cent at 40:20:20 and 7.86 per cent at 60:40:40 kg NPK ha^{-1} respectively as compared to highest dose of fertilizer 80:60:60 kg NPK ha^{-1}. Haulm yield at harvest mainly depends on the dry matter production per plant. It increased linearly with time up to 90 DAS and then declined due to defoliation of leaves. But, the persistence of leaves was more at higher fertilizer levels, therefore dry matter was higher compared to lower fertilizer levels. Such as increase in dry matter production could be attributed to increase in number of leaves, number of branches (primary and secondary) and number of spikes per plant [2]. With respect to haulm yield combination of spacing and fertilizer levels did not show any significant influence.

3.3 Quality Parameters of Chia Crop

The data on quality parameters of Chia seeds like oil, protein and fatty acid composition as influenced by different spacing and fertilizer levels are presented in Table 5. Among the different levels of spacing, the spacing of 60 × 30 cm resulted into higher protein content and oil content which was statistically superior to other spacing 45 × 30 cm, 60 × 15 cm and 45× 15 cm. However with respect to oil content spacing of 60 × 30 cm was at par with spacing of 60 × 15 cm and last three values were statistically on par with each other. The different spacing levels did not show any significant influence on fatty acid composition of Alpha linolenic acid, Linoleic acid, Oleic acid, Palmitic acid and Stearic acid. The oil content increased significantly at wider spacing of 60 × 30 cm these was supported by Malik et al. [22] reported that the crop was planted on ridges (60 cm) and interplant spacing as 30 cm resulted in significantly higher seed oil contents than that in other treatments.

The application of higher level of fertilizer 80:60:60 kg NPK ha^{-1} recorded higher protein content which was statistically on par with 60:40:40 kg NPK ha^{-1} and significantly superior to lower fertilizer level 40:20:20 kg NPK ha^{-1}. These results are in line with the finding of Mary et al. [24] who stated that fertilizer level of 90:60:75 kg NPK/ha recorded high protein content (23.85%) and was significantly superior to other fertilizer levels of 30:20:25 kg NPK/ha and 60:40:50 kg NPK/ha (20.17- 21.50 %). Similar results were also reported by Samantha et al. [25] in chia. The results confirmed the findings of earlier researchers on various crops who pointed out that addition of more amount of the nitrogen resulted into more protein content in seeds, (Hocking and Mason, [26]; Mumtaz Akhtar et al., [27] and Akbari et al., [28]. In contrast the lowest fertilizer dose of 40:20:20 kg NPK ha^{-1} was registered significantly higher oil content which was statistically superior to other levels of fertilizer 60:40:40 kg NPK ha^{-1} and 80:60:60 kg NPK ha^{-1} . Mary et al. [24] also reported that The lowest fertilizer treatment of 30:20:25 kg NPK/ha registered high oil content (30.64%) and was significantly superior to other fertilizer levels of 90:60:75 kg NPK/ha and 60:40:50 kg NPK/ha (26.20% and 27.94 % respectively). The results confirmed the findings of the earlier researchers on various crops who pointed out that oil content decreased with the increasing rate of nitrogen Saleem et al, [29]. Akbari et al. [28] in sunflower suggested that the high N-rate increases the amino acids synthesis in the leaves, and this stimulates the accumulation of protein in the seed rather than oil content. Further ppresence of nitrogen compounds in seed oil complicates the procedure of oil extraction and increases the amount of undesirable materials [30]. The extent of decrease that nitrogen had on oil concentration varied with the site and the time of application of the nitrogen fertilizers and varied depending on different climatic conditions prevailed during growing season [26].

The different fertilizer levels did not show any significant influence on fatty acid composition except Alpha linolenic acid in seeds. The lower fertilizer level that is 40:20:20 kg NPK ha^{-1} applications had shown a significant difference in fatty acid content (Alpha-linolenic acid) recorded 55.65 % which was on par with level of 60:40:40 kg NPK ha^{-1} (54.24 %) and superior to over 80:60:60 kg NPK ha^{-1} (52.18%). Mary et al. [24] also reported the lower fertilizer level contributed more for ALA content in oil. Similar results shown by Silva et al. [31] and reported that on average,

Table 4. Influence of spacing and fertilizer levels on yield attributes and yield of Chia

Treatments	Days to 50 percent flowering	Days to physiological maturity	No of spikes plant^{-1}	Seed yield plant^{-1} (g)	Test weight (g)	Seed yield (kg ha^{-1})	Haulm yield (kg ha^{-1})
Spacing (S)							
S_1: 45 × 15 cm	78.78	116.22	48.69	5.06	1.34	705	2986
S_2: 45 × 30 cm	80.44	118.33	67.32	12.81	1.37	915	4140
S_3: 60 × 15 cm	79.89	117.00	60.72	7.82	1.36	814	3457
S_4: 60× 30 cm	81.78	119.89	81.68	18.62	1.40	1015	4765
S.Em±	0.86	1.13	0.97	0.21	0.03	28.78	152.44
CD (P=0.05)	-	-	2.85	0.61	-	84.42	447.10
Fertilizer levels (F)							
F_1: 40:20:20 kg NPK ha^{-1}	79.11	115.92	55.57	9.56	1.35	709	3542
F_2: 60:40:40 kg NPK ha^{-1}	80.34	118.33	65.97	11.02	1.36	857	3844
F_3: 80:60:60 kg NPK ha^{-1}	81.22	119.33	72.26	12.65	1.38	1020	4124
S.Em±	0.75	0.98	0.84	0.18	0.02	24.93	132.02
CD (P=0.05)	-	-	2.47	0.53	-	73.11	387.20
Interaction (S×F)							
S.Em±	1.49	1.96	1.69	0.36	0.04	49.85	264.04
CD (P=0.05)	NS	NS	4.95	1.06	NS	146.21	NS

Table 5. Influence of spacing and fertilizer levels on protein (%), oil content (%) and fatty acid compositions (%) in Chia

Treatments	Protein content (%)	Oil content (%)	Fatty acid composition (%)				
			ALA	LA	OA	PA	SA
Spacing (S)							
S_1: 45 × 15 cm	21.15	27.70	53.25	23.00	10.78	8.52	3.92
S_2: 45 × 30 cm	22.17	28.17	54.21	22.34	12.11	9.05	4.11
S_3: 60 × 15 cm	21.52	28.72	53.89	22.39	11.20	9.13	4.14
S_4: 60× 30 cm	22.93	29.44	54.75	21.89	12.52	9.16	4.37
S.Em±	0.21	0.42	0.81	0.73	0.58	0.30	0.19
CD (P=0.05)	0.62	1.24	NS	NS	NS	NS	NS
Fertilizer levels (F)							
F_1: 40:20:20 kg NPK ha^{-1}	20.79	30.96	55.65	22.55	11.16	8.59	3.86
F_2: 60:40:40 kg NPK ha^{-1}	22.37	28.42	54.24	22.43	11.69	8.94	4.10
F_3: 80:60:60 kg NPK ha^{-1}	22.67	26.14	52.18	22.23	12.10	9.37	4.45
S.Em±	0.18	0.36	0.70	0.63	0.50	0.26	0.17
CD (P=0.05)	0.54	1.07	2.06	NS	NS	NS	NS
Interaction (S×F)							
S.Em±	0.36	0.73	1.40	1.26	1.00	0.53	0.34
CD (P=0.05)	NS	NS	NS	NS	NS	NS	NS

the fatty acids can be ranked in the following order of abundance: linolenic acid (C18:3) > linoleic acid (C18:2) > palmitic acid (C16:0) > oleic acid (C18:1) > stearic acid (C18:0). Ixtaina et al. [3] reported a similar distribution between the fatty acids for chia oil obtained from solvent extraction (n-hexane) and pressing. The interaction of different spacings and fertilizer levels did not show any significant difference in protein content, oil yield and fatty acid composition of oil in Chia seeds.

4. CONCLUSION

The study's findings highlighted several significant outcomes regarding Chia crop growth and yield based on varying spacing and fertilizer levels. Wider spacing of 60 × 30 cm demonstrated superior results in various aspects. It led to increased primary branches per plant (22.38), secondary branches per plant (27.69), dry matter accumulation per plant (146.09 g), leaf area per plant (4292 cm^2), number of spikes per plant (81.68), spikelets per spike (28.50), spike length (14.82 cm), seed weight per spike (0.23 g), seed yield per plant (18.62 g), overall seed yield (1015.92 kg ha^{-1}), and haulm yield (4765.26 kg ha^{-1}), along with higher protein (22.93%) and oil content (29.44%). This wider spacing of 60 × 30 cm outperformed the 45 × 30 cm, 45 × 15 cm, and 60 × 15 cm spacing configurations. However, the narrower spacing of 45 × 15 cm resulted in notable advantages, including taller plant height (125.57 cm), a higher leaf area index (7.19 at 90 DAS), a faster crop growth rate (24.52 g m-2 day-1 between 60-90 DAS), and a greater relative growth rate(0.0206 g g^{-1} day^{-1} between 60-90 DAS) when compared to other spacing levels.

When evaluating fertilizer levels, applying 80:60:60 kg NPK ha^{-1} led to advantageous outcomes. It produced taller plant height (125.59 cm), more primary branches (22.47), secondary branches (27.63), higher dry matter accumulation (131.47 g), increased leaf area per plant (4556 cm2), a greater number of spikes per plant (72.26), higher seed yield per plant (12.65 g), overall seed yield per hectare (1020.53 kg ha^{-1}), and greater haulm yield (4124.91 kg ha-1) at harvest. Additionally, this fertilizer level demonstrated faster Crop Growth Rate, Relative Growth Rate, and Leaf Area Index across all growth stages, compared to the other fertilizer levels, particularly the 60:40:40 kg NPK ha^{-1} and 40:20:20 kg NPK ha^{-1} levels. Notably, the lowest fertilizer level of 40:20:20 NPK kg ha^{-1} resulted in the highest oil content (30.96%) and omega-3-fatty acid (Alpha-linolenic acid) content (55.65%), while the highest fertilizer level of 80:60:60 NPK kg ha^{-1} produced the maximum protein content (22.67%).

In summary, the study emphasized the significant impact of spacing and fertilizer levels on Chia crop growth and yield, with wider spacing and appropriate fertilizer application leading to enhanced overall performance, while narrower spacing and different fertilizer ratios offered specific advantages in terms of plant height, growth rates, and nutrient content.

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