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

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}) to determine the influence of different spacing and fertilizer levels on growth, yield and quality of chia (*Salvia hispanica* L). The experiment was arranged in a statistical design of Factorial Randomized Complete Block Design (FRCBD) with three replications. The report of the study indicated that among different spacing's, 60 × 30 cm was recorded significantly higher number of number of primary and secondary branches plant^{-1}, Dry matter accumulation plant^{-1}, leaf area plant^{-1}, RGR, number of spikes plant^{-1} , seed yield plant^{-1} , seed yield , haulm yield, protein content(%) and oil content (%). However, spacing of 45 cm × 15 cm produced significantly superior plant height, CGR and LAI. Among different fertilizer levels, the application of 80:60:60 kg NPK ha^{-1} recorded significantly higher plant height , number of primary and secondary branches plant^{-1}, Dry matter accumulation plant^{-1}, Leaf area, number of spikes plant^{-1}, seed yield plant^{-1} seed yield, haulm yield, protein content(%) and oil content (%). 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 (Chen and Ravallion, 2008). 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 (Singh *et al*, 2023). 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 are more associated with multiple health benefits and wellness.

Chia (*Saliva hispanica* L.) is an annual oilseed crop belonging to the family of Lamiaceae originated in Mexico and Guatemala (Ixtaina *et al*., 2008). 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 diseases, 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 (Ayerza and Coates, 2000). 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.

Agronomic management is one of the most important aspects for the success of any crop with efficient utilization of all the resources. Investigations of the past have clearly brought out the significance of the cultural practices viz., crop geometry, irrigation, weeding and nutritional strategies are the major determinants of crop productivity. Since chia is a newly introduced crop in India, particularly in Karnataka. To maximize profits from this crop, it is essential to understand its growth and responses to inputs. It is important to study different aspects of plant population and spatial arrangement, as well as nutrient requirements, to achieve its potential yield. Standardization of location-specific agronomic practices, including appropriate spacing and fertilizer application, is necessary to popularize this crop in 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 with at elevation of 918 m above the Mean Sea Level (MSL) In Eastern Dry Zone of Karnataka (EDZ). The average annual rainfall of the zone was 820.50 mm received in 54 rainy days. The other distinct climatic feature of the experimental site has a tropical climate, characterized by high temperature and low humidity. The soil chemical analysis 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}). The experiment was set up using 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}). There were twelve treatments replicated thrice. The details of treatment combinations 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} 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 (Watson *et al.*, 1952).

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

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

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 (1967).

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

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, 1992), 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 (Kramer *et al.*, 1997) using the instrument Agilent 7890B GC, 5977AMSD. Fatty acid methyl esters (FAME) were prepared as described by Maia and Rodriguez- Amaya (1993). An analysis of data was performed as per the procedure outlined by Gomez and Gomez (1984).

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, which was on par with a spacing of 60 × 15 cm but statistically, superior over other spacing of 45 × 30 and 60 × 30 cm. 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. (2004) in basil, Yeboah et al. (2014), Bilalis *et al*.(2016) , Mary *et al*. (2018), and Singh *at al* (2023) in chia and Pooja et al. (2018) in sacred basil.

The wider spacing of 60 × 30 cm produced a significantly higher number of primary branches per plant, secondary branches per plant, Dry matter accumulation per plant and leaf area per plant (Table 3) 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 (2013) in basil, Yeboah *et al*. (2014) in chia, Mahantesh *et al*. (2017) in Japanese mint, and Mary *et al*. (2018) in chia.

Among the fertilizer levels, application of 80:60:60 kg NPK ha^{-1} noticed significantly higher plant height, primary, secondary branches, dry matter accumulation and leaf area per plant at harvest compared to other fertilizer levels i.e., 60:40:40 kg NPK ha^{-1} and 40:20:20 kg NPK ha $^{-1}$. 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*. (2004) in french basil, Coates *et al*. (2011), Kailash and kushwaha (2013) in basil, Mahantesh *et al*. ([2017) in mint, Mary *et al*. (2018) in chia, Pooja *et al*. (2018)

in sacred basil and Salman *et al*. (2019) 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.

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

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.

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.

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 matterplant^{-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*. (2018), Jaybhay *et al*. (2019).

Spacing of 45 × 15 cm produced significantly higher of leaf area index as compared to 60 × 15cm, 45 × 30 and 60 × 30 cm spacing at 30, 60, 90 DAS and at harvest. 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*. (2016) in chia who reported higher leaf area index at closer spacing compared to a wider spacing. These result were supported by Mary *et al*. (2018) 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 (2005), Coates (2011) and Mary *et al*. (2018) 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.

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

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*. (2018) in chia.

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*. (2018) in chia and Jaybhay (2019) 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*. (2001), Mary *et al*. (2018) in chia, Kwizera *et al*. (2018) 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.* (2014) 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*. (2018) 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.* (2018) who found the application of fertilizers as high as 90:60:75 kg NPK ha^{-1} increased the productivity of chia.

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

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 (Singh *et al.*, 2023). 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 number 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*. (2001) 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} 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} . 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 %). Significant differences were not observed in protein content and oil content due to interaction of spacing and fertilizer levels.

Application of higher level of fertilizer i.e 80:60:60 kg NPK ha^{-1} recorded significantly higher protein content over lower fertilizer level this might be due addition of more nitrogen fertilizers. Addition of more amount of the nitrogen resulted into more protein content in seeds (Hocking and Mason, 1993). Mumtaz Akhtar *et al*. (2001) in canola reported that protein contents increased with increasing rate of N, which showed inverse relationship with oil content. Akbari *et al*. (2011) 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. These results are in line with the finding of Mary *et al*. (2018) and Samantha *et al*. (2019) in chia.

Different fertilizer levels showed significant difference in quality parameters of chia. Protein and oil content in seeds recorded contradictory results. 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*, 2001). The higher oil content in less nitrogen applied treatment comparing to the other nitrogen levels was due to decreasing amount of the N compounds in the seed oil. Presence of nitrogen compounds in seed oil complicates the procedure of oil extraction and increases the amount of undesirable materials (Zangani, 2002). 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. The Hocking and Mason supported this in 1993 and reported that the nitrogen affect the oil content in the seed and or the nitrogen fertilizers promoting the production of protein within the seed.Similar results were supported by Montemurro and De Giorgio (2005), Keivanrad *et al*. (2012) in mustard, Mary *et al*. (2018) and Samantha *et al*. (2019) in chia.

The omega -3 and omega -6 polyunsaturated fatty acids (PUFA) are essential for the normal human growth and development and further appear to be important for the prevention and treatment of several diseases (coronary heart diseases, arthritis, inflammatory disorders). There are only low amounts of the omega-3 polyunsaturated fatty acids (PUFA) in major oil crops such as soybean, sunflower and palm oil (Dubois *et al*., 2007 and Araujo *et al*., 2010). The PUFA synthesis occurs in all plant cells and therefore PUFA are present in the leaves and roots, but mainly in seeds in varying amounts. Chia seed oil is the richest plant source of Omega-3 fatty acids (Ayerza and Coates, 1999; Ayerza and Coates, 2005 and Ayerza and Coates, 2011) therefore the study on effect of fertilizer application on fatty acid composition is important. The lower fertilizer level had shown a significant difference in different fatty acid content. The lower fertilizer level contributed more for alpha-linolenic acid content in oil. Oleic acid, palmitic and stearic acid content were recorded higher in higher fertilizer level. Ixtaina *et al*.(2011) and Silva *et al*. (2015) reported the fatty acids rank in the following order of abundance: alpha-linolenic acid (C 18:3) > linoleic acid (C 18:2) > palmitic acid (C 16:0) > oleic acid (C 18:1) > stearic acid (C 18:0).

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

4. CONCLUSION

On findings of the above-summarized results from experimentation, the following conclusions have been drawn that the crop which was grown at 60 × 30 cm and 45 × 30 spacing's were found increased all the growth parameters (except plant height) yield, yield attributes and quality parameters. However, the higher plant height was more in the spacing of 45 × 15 cm. Among the different fertilizer dosages, the application higher dose of fertilizers i.e 80:60:60 kg NPK ha^{-1} recorded significantly higher growth components, yield, yield characteristics and quality parameters compared to others. A combination of 60 × 30 cm + 80:60:60 kg NPK ha^{-1} recorded higher seed yield under the eastern dry zone of Karnataka.

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