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Chia (*Salvia hispanica* L.) production potential in western India influenced by planting date and crop geometry

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Abstract
Field trials were conducted at Agricultural Research Station, Mandor in Jodhpur during the winter months of 2017-18 and 2018-19. This study aims to decide planting date and crop geometry to improve chia growth, yield and oil production in arid and semi-arid environments. Over the two years of the study, chia crop performed better in terms of number of branches, number of inflorescences, seed yield and oil yield when planted on October 15 and October 25. The maximum seed yield was obtained when chia seeds were sown on October 15 with a spacing of 30 cm x 30 cm, followed by the same plant geometry with a planting date of October 25 (1083 kg/ha and 1016 kg/ha respectively). The crop took an average of 120 days to mature for all planting dates except 25 November and 5 December. It was concluded that in western Rajasthan conditions, chia seeds can be sown between 15-25 October with 30 cm x 30 cm crop geometry for higher seed and oil yields. The results of this study will help to develop a suitable package of practices for chia in India.

Keywords: Chia (*Salvia hispanica* L.), date of sowing, crop geometry, seed yield, oil yield

1. Introduction
Chia (*Salvia hispanica* L.) is an annual plant belonging to the Lamiaceae family, native to Mexico and Guatemala (Ixtaina *et al.*, 2008) [10]. Chia seeds are used medicinally and for other purposes. The color of the seeds varies from black, grey, black to white, is oval in shape and 1 to 2 mm in size (Bresson *et al.*, 2009) [6]. Chia seeds marketed today are mostly black-speckled seeds followed by a small but increasing proportion of white seeds (Ayerza and Coates, 2005) [3]. Chia seeds contain many antioxidants (Ixtaina *et al.*, 2008) [10]. Chia seeds have become important for human health and nutrition due to their Omega-3 fatty acid content (Vuksan *et al.*, 2010) [18]. Chia seeds are cultivated for their richness in omega-3 fatty acids and high alpha-linolenic acid content. Yeboa *et al.* (2014) [20] reported that chia seeds contain 35% fat. The oil content of the white and black seeds of chia seeds is approximately 33.8% and 32.7%, respectively. Chia seed oil has one of the highest concentrations (up to 67.8%) of α-linolenic fatty acid (Ayerza and Coates, 2005) [3]. Chia seeds are popular because they are one of the oil products rich in polyunsaturated fatty acids (PUFA), which are omega (ω)-3 and omega-6 FA. Alpha-linolenic acid (ALA) and linolenic acid (LA) are long-chain FAs and belong to the omega-3 and omega-6 groups, respectively. LA and ALA are essential for maintaining the integrity of cell membranes and are precursors of long-chain FA (Mann and Truswell, 2007) [16]. Once a staple food for indigenous people in Mexico and Guatemala, chia is now grown and marketed for its omega-3 alpha-linolenic acid (ALA) content and antioxidant properties. Today, its cultivation is not limited to America but has also spread to other regions such as Australia and Southeast Asia (Jamboonsri *et al.*, 2012) [12]. Chia seeds are a new product in India. Integrating chia crop into India's agricultural diversity will not only provide more crop options but also increase returns per unit of land.

The full potential of this new crop can only be realized when the planting time is appropriate and the crop geometry is determined for the growing area. It was found that the parameters and properties vary depending on the planting date, row spacing and intra-row spacing. Considering competition for nutrients, water and light between plants, the space between plants and numbers per hectare needs to be calculated (Karim *et al.*, 2015) [14] and (Yeboah *et al.*, 2014) [20]. Planting date is considered one of the most important deciding factors for chia seed yield, especially when planted in new climate. Therefore, this study aims to evaluate the impact of planting date and crop geometry on chia crop productivity in arid and semi-arid regions.

2. Materials and Methods

The experiment was conducted during 2017-18 and 2018-19 at Agricultural Research Station, Mandor, Jodhpur in agro-climatic zone IA (Arid Western Plains Region), Rajasthan. The area is between 26°15' north latitude and 26°45' north latitude and 73°00' east longitude and 73°29' east longitude and is at an altitude of 231 meters from mean sea level. The average daily maximum and minimum temperature during the growing season varied between 21.9 and 39.1 ^{0}C and 10.3 and 24.2 ^{0}C, respectively. Average daily humidity varied between 12.7% and 76.6% during the period. There was no rainfall received during the Rabi season.

Explaining the weather conditions during the trial is important because planting was done on different dates which affects the growth, yield and quality of the crop throughout the growing season. The weekly average temperature and relative humidity recorded at the weather station, ARS, Mandor, Jodhpur, during the experiment are shown in Figure 1.

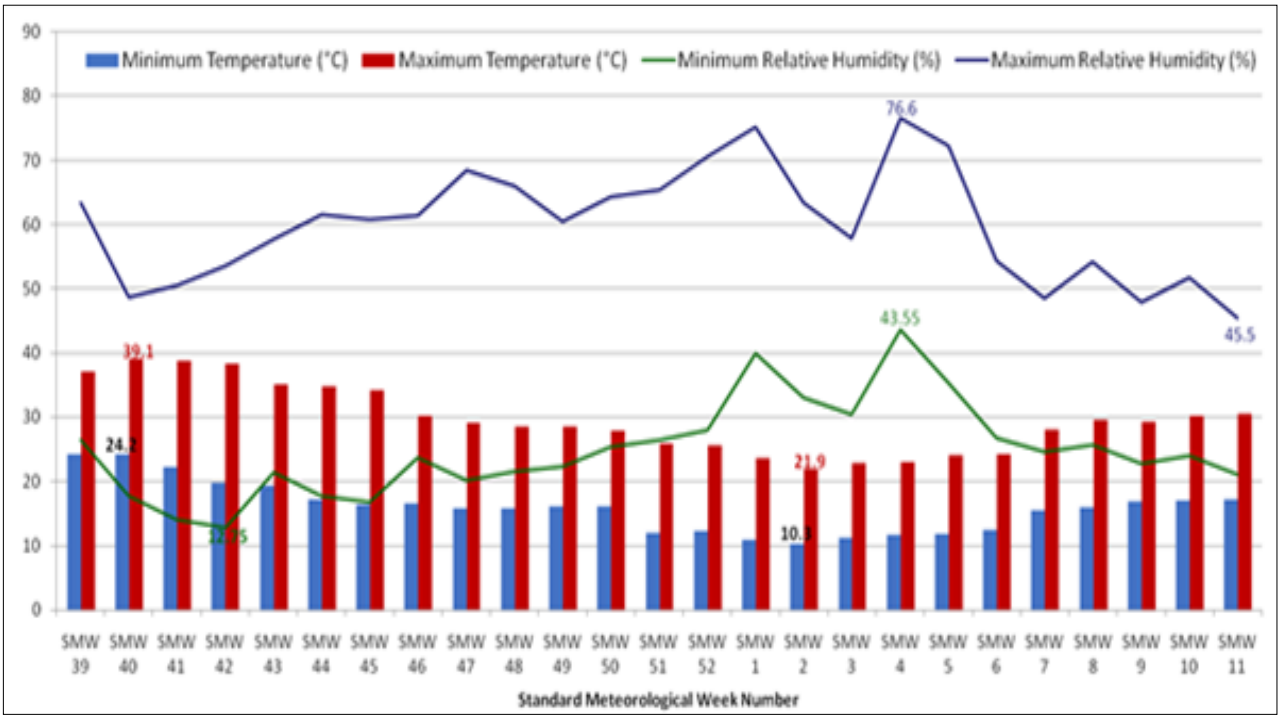

Fig 1: Mean weekly air temperature and relative humidity for the period of the experimentation

The type of the soil in the field was loamy sand, slightly alkaline, low in organic carbon (0.12%), low in nitrogen (172 kg/ha), phosphorus (24.2 kg/ha) and potassium (332 kg/ha). The experimental area was divided into an area of 3.6 m x 4.5 m according to the technical layout plan. Treatments included combinations of eight planting dates and four crop geometries. The experiment was conducted in randomized block design. The treatments were repeated three times. Chia seeds were planted during 2017 and 2018 of Rabi season on the following dates: (D1) September 25; (D2) October 5; (D3) October 15; (D4) October 25; (D5) November 5; (D6) November 15; (D7) November 25 and (D8) December 5. The crop geometry was: (P1) 30 cm × 30 cm; (P2) 45 cm × 30 cm; (P3) 60 cm × 45 cm; (P4) 90 cm x 45 cm. Before sowing, urea and diammonium phosphate were used, respectively, in the amounts of 20 kg N and 23.5 kg P2O5/ha. The seeds were sown using the 'KERA' method to a depth of 2-3 cm. Thinning was done at 15 DAS to maintain the required plants/plot for each treatment. Each treatment was manually weeded twice at 30 DAS and 60 DAS. The crop was irrigated during the branching, pre-flowering, seed formation and seed hardening stages to ensure normal growth and development of the crop. Harvesting begun from January 25 to March 18, which was the maturing time of the crop. Harvesting was done manually, the plants in each treatment were beaten to thresh them, clean seeds were collected in bags and weighted to record seed yield.

The percentage of oil in the seeds of each sample was determined by the following formula

- Accurately weighed air-dried seed (W_1) was taken and extracted with Hexane (40-60^{0}C) in Soxhlet apparatus.
- Filtered and removed the solvent under vacuum at 40^{0}C.
- The extract was dried on tarred evaporating dish (W_2) and weighted up to constant weight (W_3).
- Calculated the oil percentage with following formula.

Oil percentage: $\frac{(W_3-W_2) \times 100}{W_1}$

Where, W_1 is Weight of sample taken, W_2 is Weight of empty dish and W_3 is Weight of dish + dried residue.

(Reference: Lab guide for the analysis of A&S formulations (Pg. No 52), CCRAS, New Delhi, 2010).

Oil yield (kg/ha) was calculated by multiplying percent oil to seed yield (kg/ha) of chia.

3. Results and Discussion

Chia seeds planted on October 15 were 102.9 cm higher (Table 1a). Delay in planting caused a significant reduction in plant height. The shortest plant recorded was 63.2 cm when planted on December 5. Plant height is one of the most important growth-promoting characteristics of any crop and its variation depends on the genetic makeup of the plant and environmental conditions. This study showed that there were differences in chia plant height due to different planting times, this shows that the height of the chia plant can be affected by temperature and other environmental conditions. These results confirm previous findings by Karim *et al.* (2015) [14]. The maximum plant height observed was under 30 cm x 30 cm i.e. 94.2 cm. However, it was at par with 45 cm x 30 cm (91.5 cm). These results are consistent with Mahantesh *et al.* (2017) [15] who reported that width allows more space for growth and development, and therefore more height.

The delay in planting caused the number of chia shoots to decrease. In different planting dates, the number of branches planted on October 15 was higher at 14.3. The growth of Chia shoots is supported by higher plants. These results confirm the findings of Jadczak (2007) [11] and Fatemeh *et al.* (2007) [8]. The number of branches increased from 9.2 in crop geometry of 30 cm x 30 cm to 11.9 in geometry of 90 cm x 45 cm. This is due to the strong growth of the overall crop. These results are consistent with those obtained by Kalita *et al.* (2018) [13], Alemu (2017) [2], Karim *et al.* (2015) [14], Yagi *et al.* (2014) [19] and Umesha (1988) [17] also reported that there was an increase in the number of branches according to plant density.

In late sowing (for example, November 25 and December 5), the number of inflorescences of chia seeds decreased; the minimum number of inflorescences was 28.3 and 22.7, respectively. The maximum number of inflorescences of chia seeds was recorded as 50.4 and 48.6 when planted on October 15 and October 25, respectively. This may be because the plants will branch more and be taller when planted early. On the other hand, if planting is done on 25 November and 5 December, the number of flower clusters will be less, which may be due to the decrease in the number of branches due to the decrease in favourable environmental conditions. These results are consistent with those of Karim *et al.* (2015) [14]. Wider spaced crop produce more inflorescences than narrow ones. The maximum number of inflorescences was 42.7 at 90 cm x 45 cm, followed by 42.3 at 60 cm x 45 cm. These results confirm the findings of Freitas *et al.* (2016) [9], Abbas (2014) [1] and Umesha (1988) [17] argued that a small number of plants in an area can receive enough nutrients, water and space to produce more inflorescences per plant.

Chia crop took 120 days to mature in all dates of sowing except D7 and D8, where the seeds ripened in 111 days, causing the seed yield to reduce. The difference in growing days will be related to the difference in planting time and the environment. These results are consistent with those of Karim *et al.* (2015) [14]. However, crop geometry does not have a significant impact on crop maturity. Compared with planting on November 5, November 15, November 25 and December 5, the seed yield of plants sown on October 25 and on October 15 increased greatly to 11.2 g/plant and 9.8 g/plant, respectively. Delaying planting will cause chia seed yield per plant to decrease. The lowest seed yield per plant (3.9 g) was observed when the crop was sown on December 5. This is because the height of the plant is higher, the branches are more, and the more inflorescences per plant in early sown crop. These results are consistent with the findings of Mahantesh *et al.* (2017) [15] and Yagi *et al.* (2014) [19].

Wider spaced crops recorded more test weight as compared to narrow spaced crops of 45 cm x 30 cm and 30 cm x 30 cm but there was no statistical difference in measured test weight due to crop geometry.

Seed yield per hectare (611 kg/ha) was higher when sown on 15 October than sowing on 25 October, 5 November, 15 November and 5 December which was 90.5%, 75.5%, 58.3%, 36.5% and 24.7% of the maximum, respectively.

Slow growth at late planting results in reduced chia seed yield per hectare. The lowest yield per hectare was recorded in sowing on December 5 (151 kg/ha). Ayerza and Coates (2005) [3] reported changes in chia seed yield due to environmental effects. Karim *et al.* (2015) [14] also reported a similar effect on chia yield per hectare by delaying planting. The lowest yield per hectare was recorded in crops planted at 90 cm x 45 cm (183 kg/ha). This may be due to the wide range of plant composition. These results are consistent with the findings of Freitas *et al.* (2016) [9], Yeboah *et al.* (2014) [20] and Daneshian *et al.* (2011) [7].

Similar patterns were observed in terms of percentage oil content and oil yield of chia seeds (Table 1b). Fatmeh *et al.* (2007) reported similar results; that is, the earlier the planting date, the higher the oil content.

Table 1a: Effect of planting date and crop geometry on chia (*Salvia hispanica* L.) growth, seed yield and oil content

Treatments	Plant Height (cm)	Branches per plant	Inflorescences per plant	Main inflorescence length (cm)	Maturity days
Date of Sowing					
D_1	97.6	10.6	45.1	21.0	120
D_2	100.1	12.3	47.0	22.7	120
D_3	102.9	14.3	50.4	24.2	120
D_4	101.8	13.7	48.6	21.6	120
D_5	99.8	11.1	46.0	20.6	120
D_6	93.1	9.2	37.8	16.9	120
D_7	77.9	7.3	28.3	11.2	111
D_8	63.2	5.7	22.7	9.7	111
S.E.M±	2.5	0.24	0.74	0.40	0.33
CD (P=0.05)	7.2	0.69	2.1	1.1	0.94
Crop Geometry					
P_1	94.2	9.2	38.4	17.6	118
P_2	92.7	9.9	39.6	18.0	118
P_3	91.5	11.1	42.3	18.9	117
P_4	89.7	11.9	42.7	19.5	117
S.E.M±	1.79	0.17	0.52	0.28	0.24
CD (P=0.05)	NS	0.49	1.5	0.80	NS
CV (%)	9.5	8.0	6.3	7.5	1.0

Table 1b: Effect of planting date and crop geometry on chia seed yield and oil content

Treatments	Seed yield per plant (g)	Test weight (g)	Seed yield (kg/ha)	Oil yield (kg/ha)	Percent oil content
Date of Sowing					
D_1	7.5	1.068	323	95	29.5
D_2	9.1	1.095	465	139	30.0
D_3	11.2	1.103	611	184	30.2
D_4	9.8	1.102	553	164	29.9
D_5	8.5	1.096	461	136	29.8
D_6	6.9	1.023	356	105	29.7
D_7	5.2	0.920	223	65	29.3
D_8	3.9	0.867	151	44	29.3
S.E.M±	0.17	0.008	11	3.3	0.09
CD (P=0.05)	0.49	0.022	31	9.3	0.25
Crop Geometry					
P_1	6.7	1.02	665	196	29.3
P_2	7.4	1.03	464	138	29.5
P_3	8.2	1.04	259	78	29.8
P_4	8.7	1.04	183	56	30.1
S.E.M±	0.12	0.006	8	2.3	0.06
CD (P=0.05)	0.34	NS	22	6.6	0.18
CV (%)	7.7	2.6	9.8	9.7	1.0

3.1 Interaction of sowing date with crop geometry

The combined effect of planting date and crop geometry was significant in terms of branches per plant, number of inflorescences per plant, seed yield per plant, seed yield per hectare, oil yield per hectare and oil content [Table 2a-f]. It was found that the number of branches per plant, the number of inflorescences per plant, the seed yield per plant and the percentage of oil content reached their peak when chia seeds were sown on October 15 with crop geometry of 90 cm x 45 cm followed by 60 cm x 45 cm. However, the higher seed yield per hectare and oil yield per hectare were obtained by sowing chia seeds on 15 October at 30 cm x 30 cm and 45 cm x 30 cm crop geometries. The best combination of planting date and crop geometry in terms of yield characteristics of chia was 15 October (60 cm x 45 cm), 15 October (90 cm x 45 cm), 25 October (60 cm x 45 cm) and 25 October (90 cm x 45 cm), but on per hectare basis it was 30 cm x 30 cm with 15 October, 45 cm x 30 cm with 15 October and 30 cm x 30 cm with 25 October.

Table 2a-f. Interaction between planting date and plant geometry; including number of branches per plant, number of inflorescences per plant, seed yield per plant, seed yield per hectare, oil yield per hectare, and percentage oil content

Table 2a: Interaction (Number of branches per plant)

Treatments	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8
P_1	8.5	10.9	13.2	12.5	10.9	8.2	5.1	4.5
P_2	10.2	11.6	13.3	12.7	10.9	8.7	7.7	4.5
P_3	10.7	13.2	15.3	14.7	11.2	8.9	7.7	6.8
P_4	13.1	13.4	15.7	15.0	11.6	11.2	8.4	6.8
S.E.M±	0.49							
CD (0.05)	1.38							

Table 2b: Interaction (Number of inflorescences per plant)

Treatments	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8
P_1	44.0	46.1	49.2	48.6	45.5	32.5	21.9	19.4
P_2	45.3	46.7	48.8	47.5	45.5	36.5	26.9	19.4
P_3	45.3	47.6	51.8	48.7	45.8	41.2	31.9	25.9
P_4	45.7	47.6	51.8	49.7	47.2	41.2	32.6	25.9
S.E.M±	1.5							
CD (0.05)	4.2							

Table 2c: Interaction (Seed yield per plant)

Treatments	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8
P_1	6.3	7.9	10.2	9.2	8.2	6.0	3.2	2.9
P_2	7.0	8.5	10.6	9.2	8.4	6.9	5.7	3.0
P_3	7.6	10.0	12.0	10.3	8.5	6.9	5.7	4.9
P_4	9.3	10.0	12.2	10.6	8.9	7.8	6.3	4.9
S.E.M±	0.34							
CD (0.05)	0.97							

Table 2d: Interaction (Seed yield kg/ha)

Treatments	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8
P_1	457	796	1083	1016	849	598	281	240
P_2	432	559	659	603	553	451	328	131
P_3	215	315	430	359	268	195	159	130
P_4	187	190	274	235	173	181	124	102
S.E.M±	22							
CD (0.05)	63							

Table 2e: Interaction (Oil yield kg/ha)

Treatments	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8
P_1	134	234	320	299	249	176	82	71
P_2	127	167	198	178	163	133	96	38
P_3	64	96	131	108	81	58	47	38
P_4	56	58	85	73	53	55	37	30
S.E.M±	7							
CD (0.05)	19							

Table 2f: Interaction (Percent oil content)

Treatments	D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8
P_1	29.3	29.4	29.4	29.3	29.3	29.4	29.3	29.2
P_2	29.4	29.9	30.0	29.5	29.5	29.4	29.3	29.3
P_3	29.7	30.3	30.4	29.9	30.0	29.8	29.3	29.3
P_4	29.8	30.4	31.1	30.8	30.4	30.1	29.3	29.3
S.E.M±	0.18							
CD (0.05)	0.50							

Table 3a: Correlation coefficient and regression line showing the relationship between the independent variable (X) and the dependent variable (Y) as affected by the planting date

Independent variables (X)	Dependent variables (Y)	Correlation coefficient (r)	Regression lines		
Plant height (cm)	No. of branches per plant	0.922**	Y	=	0.195x - 7.497
No. of branches per plant	No. of inflorescence per plant	0.963**	Y	=	3.271x + 6.304
No. of inflorescence per plant	Seed yield per plant (g)	0.921**	Y	=	0.225x - 1.415
Main inflorescence length (cm)	Seed yield per plant (g)	0.907**	Y	=	0.424x - 0.088
Test weight (g)	Seed yield per plant (g)	0. 930**	Y	=	24.37x - 17.44
Test weight (g)	Seed yield (kg/ha)	0.904**	Y	=	1562.x - 1223
Seed yield per plant (g)	Seed yield (kg/ha)	0.987**	Y	=	0.015x + 1.886
Seed yield (kg/ha)	Oil yield (kg/ha)	1.000**	Y	=	0.302x - 2.456
Percent oil content	Oil yield (kg/ha)	0. 961**	Y	=	0.006x + 28.95

Table 3b: Correlation coefficients and regression lines showing the relationship between the independent variable (X) and the dependent variable (Y) as affected by the crop geometry

Independent variables (X)	Dependent variables (Y)	Correlation coefficient (r)	Regression lines		
Plant height (cm)	No. of branches per plant	-0.987**	Y	=	-0.625x + 68.12
No. of branches per plant	No. of inflorescence per plant	0.981**	Y	=	1.695x + 22.90
No. of inflorescence per plant	Seed yield per plant (g)	0.983**	Y	=	0.415x - 9.174
Main inflorescence length (cm)	Seed yield per plant (g)	0.989**	Y	=	1.013x - 11
Test weight (g)	Seed yield per plant (g)	0. 968**	Y	=	0.010x + 0.951
Test weight (g)	Seed yield (kg/ha)	-0.989**	Y	=	-22391x + 23511
Seed yield per plant (g)	Seed yield (kg/ha)	-0.995**	Y	=	-0.004x + 9.337
Seed yield (kg/ha)	Oil yield (kg/ha)	1.000**	Y	=	0.290x + 2.819
Percent oil content	Oil yield (kg/ha)	-0. 968**	Y	=	-0.005x + 30.30

Table 4a: Correlation coefficient of different variables as affected by planting dates

Variables	Plant Height	Branches per plant	No. of Inflorescence per plant	Main Inflorescence Length	Days to Maturity	Seed yield per plant	1000 Seeds Weight	Seed yield per ha	Oil yield per ha	Percent oil content
Plant height	1.000									
Branches per plant	0.922	1.000								
No. of inflorescence per plant	0.979	0.963	1.000							
Main inflorescence length	0.957	0.954	0.991	1.000						
Days to maturity	0.938	0.826	0.921	0.920	1.000					
Seed yield per plant	0.918	0.936	0.921	0.907	0.800	1.000				
1000 seeds weight	0.988	0.936	0.993	0.978	0.945	0.930	1.000			
Seed yield per ha	0.889	0.974	0.921	0.907	0.800	0.987	0.904	1.000		
Oil yield per ha	0.885	0.974	0.918	0.906	0.795	0.987	0.900	1.000	1.000	
Percent oil content	0.823	0.918	0.861	0.881	0.778	0.947	0.947	0.957	0.961	1.000

Table 4b: Correlation coefficient of different variables as affected crop geometries

Variables	Plant Height	Branches per plant	No. of Inflorescence per plant	Main Inflorescence length	Days to Maturity	Seed yield per plant	1000 Seeds Weight	Seed yield per ha	Oil yield per ha	Percent oil content
Plant height	1.000									
Branches per plant	-0.987	1.000								
No. of inflorescence per plant	-0.943	0.981	1.000							
Main inflorescence length	-0.983	0.999	0.977	1.000						
Days to maturity	0.865	-0.933	-0.969	-0.940	1.000					
Seed yield per plant	-0.987	0.995	0.983	0.989	-0.917	1.000				
1000 seeds weight	-0.919	0.945	0.977	0.931	-0.905	0.968	1.000			
Seed yield per ha	0.968	-0.982	-0.986	-0.972	0.915	-0.995	-0.989	1.000		
Oil yield per ha	0.968	-0.982	-0.987	-0.972	0.916	-0.995	-0.988	1.000	1.000	
Percent oil content	-0.995	0.997	0.961	0.996	-0.907	0.989	0.920	-0.968	-0.968	1.000

4. Conclusion

This article explains the best planting time and optimum spacing of chia sowing in the Western Indian region. Chia crop can be sown between 15 October and 25 October with 30 cm x 30 cm crop geometry to get higher seed and oil yield in similar conditions of Rajasthan and India. The findings will help to develop a suitable package of practices for chia in the country.

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