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Impact of moisture stress on root growth in chia (*Salvia hispanica* L.) genotypes

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Abstract
At the College of Horticulture in Mudigere, a protected pot experiment was carried out to investigate the impact of moisture stress on the performance of four local genotypes of chia *viz.*, H. D. Kote local, Mysore local, T. Narasipura local and Nanjangud local with three moisture stress levels *i. e.* 50, 75 and 100% (Control) of field capacity. The experiment was laid out in a factorial completely randomized design with three replications. The study's findings suggested that different physiological constraints caused different genotypes to exhibit varying results on various attributes. Genotype H. D. Kote local showed better performance concerning root growth attributes. While, the genotype Mysore local was found inferior. Severe water stress (50% of FC) reduced number of roots per plant, root length (cm) and root thickness (mm). However, mild stress (75% of FC) was found beneficial for better root growth of chia genotypes.

Keywords: Water stress, field capacity, genotype, root growth

1. Introduction

Salvia hispanica L., commonly known as chia, is an annual oilseed plant in the Lamiaceae family. Native to southern Mexico and northern Guatemala, it's now grown in both tropical and subtropical climates. Chia is a dicotyledonous plant that grows to about a meter tall. It has hairy, ribbed, square-shaped stems and opposite, serrated leaves that are 4 to 8 cm long and 3 to 5 cm wide. The plant's flowers are hermaphroditic and grow in dense clusters on a spike, protected by small bracts. The fruit of the chia plant is a schizocarp, which splits into four separate fruitlets called mericarps or nutlets. These fruitlets are what are commercially referred to as "seeds," though the true seed is inside each one. Chia seeds are small (1-2 mm), oval, smooth, and shiny, with colors ranging from black, gray, and black-spotted to white (Ayerza and Coates, 2005) [2].
Chia is regarded as a super-food crop because of its high nutritional content. Comparing the seed to other natural sources, it has the highest amount of α-linolenic acid (60 percent) and roughly 25-38% oil by weight (Ayerza, 1995) [3] and also higher levels of protein (19-23%) in addition to other important nutritional components, such as vitamins, minerals and natural antioxidants (Coates and Ayerza, 1996) [4].
Despite the threat of malnutrition, India has very limited cultivation and consumption of chia. The country currently imports chia seeds from countries like Australia, Bolivia, and the U.S., where they are sold for around Rs. 2,000 per kg. Given its functional components, chia has significant potential in India's health, food, animal feed, pharmaceutical, and nutraceutical industries (Mary, 2017) [9]. As an introduced crop, chia is gaining traction in India, with its cultivated area slowly expanding. This offers a promising future for both Indian farmers and the agricultural market. However, because it's a relatively new crop to the country, particularly in Karnataka, there's limited research on its agronomic management. Recently, farmers in the Mysore and Chamrajanagara districts of Karnataka have begun growing chia with technical support from the Central Food Technological Research Institute (CFTRI) in Mysore.
Contemporary agriculture faces significant obstacles due to continuous exposure to both biotic and abiotic stressors. Drought represents a critical abiotic stress that profoundly impairs crop production and yield potential. Water limitation induces systemic changes in plants, beginning at

the level of cellular metabolism and extending to the morphological development of roots and shoots, consequently determining the final yield.

Furthermore, unpredictable rainfall and declining groundwater supplies in Karnataka and India have made water a scarce resource in recent years. The primary limiting environmental factor in the majority of the world's regions is water stress (Valliyodan and Nguyen, 2006) [13]. *Salvia hispanica* L. has been described as a species highly tolerant to water deficit, but in ecological-adaptive responses to water deficits are unknown (Silva *et al.*, 2018) [11]. Though the roots are not an economical part in chia, they still are an integral part of any plant for that matter. Studying roots under water stress is important because roots are the primary site of water absorption. Understanding how they respond to drought helps in developing crops that are more water-efficient and resilient to climate change. This knowledge is crucial for ensuring food security in a world with increasingly limited water resources. Since chia is said to react fairly to drought, it is necessary to investigate how various moisture stress levels affect this crop's performance. The current study was designed to examine the genetic potential of four local chia genotypes under three different levels of moisture stress.

2. Materials and Methods

2.1 Experimental details

The study was set up as a pot experiment inside the polyhouse of the Medicinal Plants block at the College of Horticulture, Mudigere. The study area lies between 13^0 08' to 13^0 53' Northern latitude and between 75^0 04' to 76^0 21' Eastern longitude and located at an altitude of 982 m above mean sea level. Statistically, the study followed a Factorial Completely Randomized Design and included three replications. Treatment combinations were four genotypes *viz*., H. D. Kote local (V_1), Mysore local (V_2), T. Narasipura local (V_3) and Nanjangud local (V_4) with three levels of moisture stress *viz*., 50% (S_1), 75% (S_2) and 100% (S_3 - Control) of field capacity. Thus, there were twelve treatment combinations *viz*., $T_1 = V_1S_1$, $T_2 = V_1S_2$, $T_3 = V_1S_3$, $T_4 = V_2S_1$, $T_5 = V_2S_2$, $T_6 = V_2S_3$, $T_7 = V_3S_1$, $T_8 = V_3S_2$, $T_9 = V_3S_3$, $T_{10} = V_4S_1$, $T_{11} = V_4S_2$ and $T_{12} = V_4S_3$.

2.2 Plant material and growing conditions

The chia seeds from each genotype were gathered from their respective locations in Karnataka' Mysore district. Plugs filled with sterile coco peat were used to raise the seedlings in portrays. Twenty days after they were sown, the seedlings were prepared for transplantation. 288 plastic pots with a capacity of 22 litres and a depth of 32 cm were used in the experiment. After being sterilized with formalin, red soil was covered for ten days with black polythene. After mixing soil, sand and farm yard manure (FYM) in a 2:1:1 ratio, the pots were filled.

Twenty-day-old seedlings were transplanted into pots according to the experimental layout. To prevent fungal disease, they were immediately irrigated and drenched with a 0.2 per cent Bavistin solution. At 12 days after transplanting (DAT), seedlings were thinned to one plant per pot. Plants were irrigated every 3-4 days, and later every 6-7 days, until 20 DAT, by which point all had reached the 6-leaf stage. At 20 DAT, the moisture stress treatment was imposed. Weeding was performed as needed, and all plants were harvested at 90 DAT.

2.3 Measurements

Number of roots per plant, root length (cm) and root thickness (mm) were recorded.

2.3.1 Root growth parameters

2.3.1.1 Number of roots per plant

The total numbers of primary, secondary and tertiary roots were counted by uprooting selected plants at 30, 60 and 90 DAT and mean value was calculated and expressed as number of roots per plant.

2.3.1.2 Root length (cm)

The length of the root was measured in three randomly selected plants at 30, 60 and 90 DAT from collar region to tip (tail part) of the primary root and average root length was expressed in centimetre.

2.3.1.3 Root thickness (mm)

The thickness of the primary root of each selected plant at 30, 60 and 90 DAT was measured using digital vernier caliper of range 0 to 200 mm and expressed in millimeter.

2.4 Statistical analysis

Fisher's method of analysis of variance, as described by Gomez and Gomez (1984) [5], was used to statistically analyze the morphological and physiological parameter data gathered from the experiment. The level of significance used in the 'F' test was at 5 per cent. The critical difference (CD) values are given at 5 per cent level of significance, wherever the 'F' test was significant.

3. Results and Discussion

Due to differing physiological constraints, different genotypes displayed varying results on various attributes. Severe water stress (50% of FC) caused a significant decrease in number of roots, root length (cm) and root thickness (mm). However, mild stress (75% of FC) registered better root growth (Table 1).

Number of roots per plant, in all the stages of crop growth till harvest, was maximum in genotype H. D. Kote local (11.33, 18.83 and 20.17 at 30 DAT, 60 DAT and 90 DAT respectively) at 75% of FC and minimum in genotype Mysore local (6.67, 11.33, 15.83 at 30 DAT, 60 DAT and 90 DAT respectively) at stress of 50% of FC. The genetic composition of various genotypes, their interaction with growing conditions, and their expression may be the cause of the variation in the number of roots. According to Srivastava (2017) [12], developmental morphology is innate, but a genotype's expression will change depending on the growing environment, leading to phenotypic plasticity.

It's possible that more effective osmotic modification in roots than in shoots accounts for the rise in the number of roots under less severe stress (Sharp and Davies, 1979) [10]. Limited data suggests that, water stress can cause an increase in root growth when compared with the situation in well-watered plants (Hsiao and Acevedo, 1974) [6]. Ashraf and Harris (2006) [1] reported that under water deficit conditions, shoot growth is more inhibited as compared with the root growth. Similar observations were reported by Sharp and Davies (1979) [10] in maize.

Root length (cm), in all the stages of crop growth till harvest, was maximum in genotype H. D. Kote local (8.83 cm, 13.50 cm and 19.08 cm at 30 DAT, 60 DAT and 90 DAT respectively) at 75% of FC and minimum in genotype Mysore local (5.08 cm, 9.96 cm and 14.25 cm at 30 DAT, 60 DAT and 90 DAT respectively) at stress of 50% of FC.

This may be due to the stress adaptability mechanism existing in the genotypes to survive under extreme water deficit conditions. The variation in the root length might be due to the genetic makeup of different genotypes and their interaction with growing conditions. The above results were found in agreement with Vikas *et al*. (2009) [14] in rice.

Mild stress had a positive effect on root length compared to no stress (control) and severe stress. Although it is well established that root length in plants under water stress, will be increased in search of water when compared with unstressed plants, but the contradictory results obtained in the present study could be due to the imposition of severe drought stress of about 50 per cent of FC. Hence, we hypothesis that root length must have increased in the milder stress level when the plant senses drought and might have inhibited in severe stress due to direct shortage in water content, indirectly due to the insufficiency of food reserves. Similar observations were reported by Weaver (1926) [15] in corn and Kondo *et al*. (2000) [7] in rice.

Root thickness (mm), in all the stages of crop growth till harvest, was maximum in genotype H. D. Kote local (0.43 mm, 4.43 mm and 5.08 mm at 30 DAT, 60 DAT and 90 DAT respectively) at 75% of FC and minimum in genotype Mysore local (0.25 mm, 2.13 mm and 2.76 mm at 30 DAT, 60 DAT and 90 DAT respectively) at stress of 50% of FC. The variation in the root thickness might be due to the genetic makeup of genotypes.

Mild stress had a positive effect on root thickness compared to no stress (control) and severe stress. Under mild water deficit, plants respond to water stress by increasing the root growth both vertically and laterally (Weaver, 1926) [15]. It most likely happens when mild water stress prevents more shoot growth than photosynthesis, which leaves more carbohydrates available for root growth (Kramer, 1983) [8]. Similar observations were reported by Yang *et al*. (2016) [16] in tomato.

Table 1: Effect of moisture stress on root growth (No. of roots, root length and root thickness) in chia (*S. hispanica* L.) genotypes

Genotype	Moisture stress	No. of roots per plant			Root length (cm)			Root thickness (mm)		
		30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT	30 DAT	60 DAT	90 DAT
H. D. Kote local	50% of FC	10.17	15.33	16.67	6.45	10.93	16.83	0.32	2.45	3.33
	75% of FC	11.33	18.83	20.17	8.83	13.50	19.08	0.43	4.43	5.08
	100% of FC	11.17	17.16	18.08	7.83	12.50	17.97	0.36	3.76	4.21
Mysore local	50% of FC	6.67	11.33	15.83	5.08	9.96	14.25	0.25	2.13	2.85
	75% of FC	8.83	12.00	16.70	6.63	11.55	16.32	0.31	2.86	3.18
	100% of FC	7.83	11.66	16.12	6.24	11.05	15.75	0.27	2.30	3.06
T. Narasipura local	50% of FC	6.83	11.83	16.17	5.78	10.33	14.92	0.29	2.28	2.76
	75% of FC	9.50	13.00	16.92	7.23	11.98	17.08	0.32	2.90	3.31
	100% of FC	8.83	12.50	16.42	7.17	11.41	16.42	0.30	2.58	3.16
Nanjangud local	50% of FC	10.00	13.16	16.33	6.32	10.56	16.23	0.32	2.84	3.95
	75% of FC	10.83	14.33	17.68	7.75	12.35	17.78	0.35	3.36	4.05
	100% of FC	10.67	14.16	17.15	7.45	11.93	17.32	0.34	3.16	4.01
S.Em ±		0.60	0.30	0.12	0.57	0.11	0.10	0.01	0.22	0.20
CD (P=0.05)		NS	0.91	0.37	NS	0.34	0.32	NS	0.66	0.62

FC = Field capacity

DAT = Days after transplanting; NS = Non-significant

4. Conclusion

The study's findings suggested that different physiological constraints caused different genotypes to exhibit varying results on various attributes. Genotype H. D. Kote local showed better performance concerning growth attributes. While, the genotype Mysore local was found inferior. Severe water stress (50% of FC) reduced number of roots per plant, root length (cm) and root thickness (mm). However, mild stress (75% of FC) was found beneficial for better root growth of chia genotypes.

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