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Salt Mediated Morpho-Anatomical and Nutrient Responses in Hydroponically Grown Tomato (*Solanum lycopersicum* L.) Under Different Organic Media

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Abstract | **Original Research Article**

Tomato (Solanum lycopersicum L.), a member of the Solanaceae family, is one of the most widely cultivated and consumed fruit crops globally. It is low in calories and rich in essential nutrients such as vitamin C and potassium, as well as antioxidants that help lower the risk of chronic diseases like cancer, diabetes, and cardiovascular disorders. Hydroponic systems offer a cost-effective and high-yield alternative to conventional cultivation methods by providing optimal growing conditions. This study was conducted at the Aquaponics facility of Government College Women University Faisalabad to evaluate the structural, growth, and nutrient responses of different tomato varieties cultivated hydroponically using various organic media under salt stress conditions. A Completely Randomized Design (CRD) with three replications was used. Three tomato varieties—Cherry Tomato, Hybrid Tomato, and Sagar F1—were grown hydroponically in four types of soilless media: cocopeat, Hoagland solution, sawdust, and sugarcane bagasse, with nutrient supply provided via half-strength Hoagland's solution. Salt stress (50 mM NaCl) was applied after three months. Morphological traits (shoot/root length, fresh/dry weights) and anatomical traits (cross-sectional area, cortical thickness, cortical cell area, and phloem thickness) were recorded. Data were analyzed using ANOVA. Results indicated that, except for phloem thickness, Hoagland and cocopeat media yielded the best growth and structural development. The Sagar F1 variety outperformed the Cherry and Hybrid varieties. Salt stress negatively affected plant growth, increasing sodium ion accumulation and reducing potassium levels. Overall, Hoagland and cocopeat media provided the most favorable outcomes across all parameters studied.
Keywords: Hydroponics, Tomato varieties, Salt stress, Soilless media, Nutrient response.

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1. INTRODUCTION

Tomatoes (Solanum lycopersicum) are among the most significant horticultural and vegetable crops globally due to their nutritional, economic, and culinary importance. As members of the Solanaceae family, tomatoes, along with potatoes, eggplants, and peppers, contribute substantially to human diets (Jagatheeswari, 2014). They are widely consumed in various forms such as sauces, soups, juices, and salads due to their high content of carotenoids, particularly lycopene, polyphenols, and vitamins A, C, and E, which are known to enhance sensory and health-related properties (Collins *et al.*, 2022; Tohge and Fernie, 2015; Viuda-Martos *et al.*, 2014). In Nigeria and globally, tomatoes are a primary dietary source of antioxidants and essential nutrients, making them the third most consumed vegetable after potatoes and sweet potatoes (Olaniyi *et al.*, 2010; Hao *et al.*, 2020; Rai *et al.*, 2013).

Tomatoes are extensively grown in various climatic regions and are often cultivated in both dry and wet seasons, particularly in greenhouses or open fields using diverse cultivation methods (Shimu *et al.*, 2014; Komosa *et al.*, 2011). Organic substrates like coconut coir and composts have replaced traditional rock wool in many countries for improved sustainability (Barret *et al*., 2016; Xiong *et al*., 2017). In countries such as Japan and Canada, tomato farming holds substantial economic value (Kanayama, 2017; Ontario Ministry of Agriculture and Food, 2003a). Tomato products provide essential nutrients, supplying up to 85% of the daily requirement for children and 60% for adults in vitamin C intake, along with iron and vitamins A and B (Wtodarczyk *et al*., 2022).

In Bangladesh, tomatoes are grown on 27,000 hectares, producing 368,000 tons annually at an average yield of 13.57 tons/ha. Major growing regions include Chittagong, Jessore, Comilla, and Rajshahi (Chakma *et al*., 2019). Seedling production quality depends significantly on the growing medium's composition, requiring optimal water retention, drainage, and nutrient supply (Nwofia and Okwu, 2015; Olaria *et al*., 2016). Media such as cocopeat, vermicompost, and rice husk ash support effective seedling development, with vermicompost considered especially beneficial (Mathowa *et al*., 2016; Bhat *et al*., 2013; Vaughn *et al*., 2011). Soilless cultivation, particularly hydroponics, is increasingly used worldwide to overcome soil limitations and improve sustainability in food production (Fussy and Papenbrock, 2022; Machado and Serralheiro, 2017).

MATERIAL AND METHODS

The experiment was conducted in Aquaponics setup established at GC Women University Faisalabad to assess the structural changes, growth and nutrient responses of tomato varieties raised hydroponically in different organic media under normal and salt stress condition. The experiment was arranged in Completely Randomized Design (CRD) with three replicates. Three tomato varieties were used in this experiment. These three varieties (cherry Tomato, Sagar F1 tomato and Hybrid Tomato) were grown in soilless organic media hydroponically. The plants was grown in plastics pipes half filled with four organic media i.e., Hoagland, Cocopeat, sugarcane bagasse and sawdust. Nutrients were supplied by using half strength Hoagland solution. The plants were subjected to salt stress i.e., 50mM NaCl after three months of experiment. The data for various morpho-anatomical and nutrient responses was determined at the flowering stage.

2.1. Morphological Parameters

Following morphological parameters were recorded

- Shoot length
- Root length
- Root fresh and dry weight
- Shoot fresh and dry weight

2.2. Anatomical Studies

For the anatomical studies, a selected portion of root and stem was taken from the lateral branch and preserved first in a fixative (formalin acetic alcohol) (formaline 5%, acetic acid 10%, ethyl alcohol 50% and distilled water 35%) for 24 hours and then in a preservative (acetic alcohol) (v/v 25% acetic acid and 75% ethyl alcohol) for long term preservation. A 2 cm piece was taken from each organ from each plant for anatomical studies. Free-handed sectioning slides were prepared by serial dehydrations in ethanol using the standard double-stained technique of safranine and fast green stains. Photographs were taken with the help of a camera-equipped microscope. The following anatomical features were noted.

Root Anatomy

- Root cross-sectional area
- Epidermis thickness
- Cortex thickness
- Cortical cell area
- Vascular bundle thickness

Stem Anatomy

- Stem cross-sectional area
- Epidermis thickness
- Cortex thickness
- Cortical cell area
- Phloem thickness

2.3. Ionic Contents

Dried ground material (0.5 g in each tube) was taken in digestion tubes and 5 mL of concentrated H_2SO_4 were added to each tube (Wolf, 1982). All the tubes were incubated overnight at room temperature. Then 0.5 mL of H_2O_2 (35%) was poured down the sides of the digestion tube, ported the tubes in a digestion block and heated at 350ºC until fumes were produced. They were continued to heat for another 30 minutes. The digestion tubes were removed from the block and cooled. 0.5 mL of H_2O_2 was slowly added to each tube and placed the tubes back into the digestion block. The above step was repeated until the cooled digested material was colorless. The volume of the extract was made up to 50 ml. The extract was filtered and used for determining Na^+, K^+ and Ca^{2+}.

Determination of Na^+, K^+ and Ca^{2+}

Na^+, K^+ and Ca^{2+} cations were determined with a flame photometer (Jenway, PFP-7). A graded series of standards (ranging from 5 to 25 mg L-1) of Na^+, K^+ and Ca^{2+} were prepared and standard curves were drawn. The values of Na^+, K^+ and Ca^{2+} from flame photometer were compared with standard curves and total quantities were computed.

2.4. Statistical Analysis

The recorded data was subjected to analysis of variance (ANOVA) (Steel *et al*., 1997)

RESULTS

3.1. Morphological Attributes

3.1.1. Shoot Length

The analysis of variance (ANOVA) for the shoot length of tomato varieties grown in different organic media and salt stress is presented in Table 1 in which varieties, media and salt levels showed highly significant responses. Moreover, the interactions between varieties and media, varieties and salt and media and salt were also highly significant. Sagar F1 variety showed the highest value of shoot length in all growth media as compared to the hybrid and cherry varieties. The maximum shoot length was observed in Sagar F1 variety in the Hoagland medium followed by Cocopeat, while the minimum length was noted in the sawdust medium. In the hybrid variety, the minimum value of this parameter was noted in the sawdust medium, and the larger lengths were reported in the Hoagland and Cocopeat media. Cherry variety showed the minimum shoot lengths in all growth media as compared to others. The salt stress resulted in the reduction of shoot length in all growth media in all varieties. The smallest shoot length under salt stress was noted in the cherry variety in the sawdust medium, while the higher shoot lengths were reported under Hoagland and Cocopeat media (Fig.1).

Table 1: Analysis of variance (ANOVA) of shoot length of tomato varieties under salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	3478.40	1739.20	473.23	.0000 ***
Media (M)	3	14238.69	4746.23	1291.45	.0000 ***
Salt (S)	1	1580.43	1580.43	430.03	.0000 ***
V x M	6	192.67	32.11	8.73	.0000 ***
V x S	2	78.23	39.11	10.64	.0001 ***
M x S	3	77.01	25.67	6.98	.0005 ***
V x M x S	6	35.69	5.94	1.61	.1624 ns
Error	48	176.40	3.67		

*** =0.001 level of significance, ns= level of non-significance

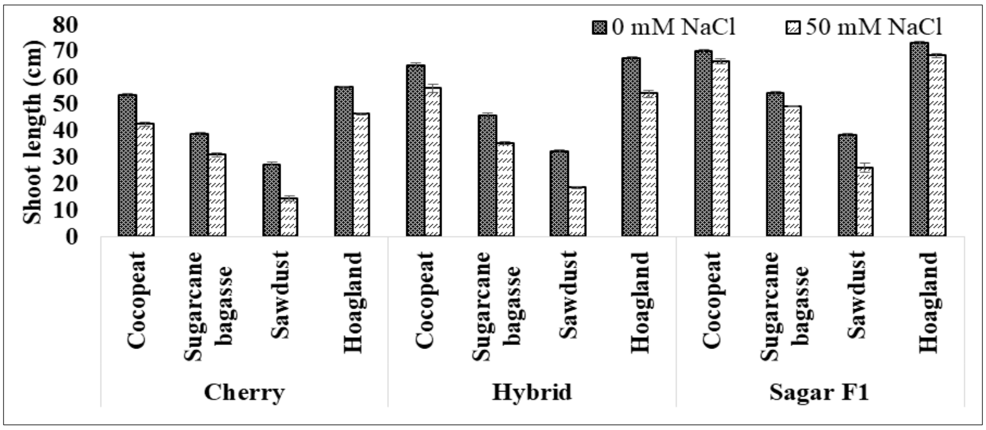


Fig. 1: Shoot length of tomato varieties under salt stress and different organic media

3.1.2. Root Length

The analysis of variance (ANOVA) for the root length of tomato which is grown in four organic media under normal conditions and salt stress presented in table 2. Only varieties and media showed highly significant interaction. Cherry varieties showed the lowest values of root length as compared to the Hybrid and Sagar F1 varieties. Sagar F1 showed highest values in the table. The minimum values were observed in the Cherry varieties in the Sawdust media. While the maximum values were in Sagar F1 varieties in Hoagland media. Hoagland and Cocopeat media reported the longer lengths in all varieties. Salt stress reduced root length in all growth media and in all types. The cherry variety had the shortest root length under salt stress in the sawdust medium, while the highest root lengths were reported in the Hoagland and Cocopeat media (Fig.2).

Table 2: Analysis of variance (ANOVA) of root length of tomato varieties under salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	956.47	478.23	134.87	.0000 ***
Media (M)	3	7349.77	2449.92	690.96	.0000 ***
Salt (S)	1	521.05	521.05	146.95	.0000 ***
V x M	6	118.06	19.67	5.54	.0002 ***
V x S	2	6.44	3.22	0.90	.4096 ns
M x S	3	14.25	4.75	1.34	.2723 ns
V x M x S	6	8.19	1.36	0.38	.8849 ns
Error	48	170.19	3.54		

*** =0.001 level of significance, ns= level of non-significance

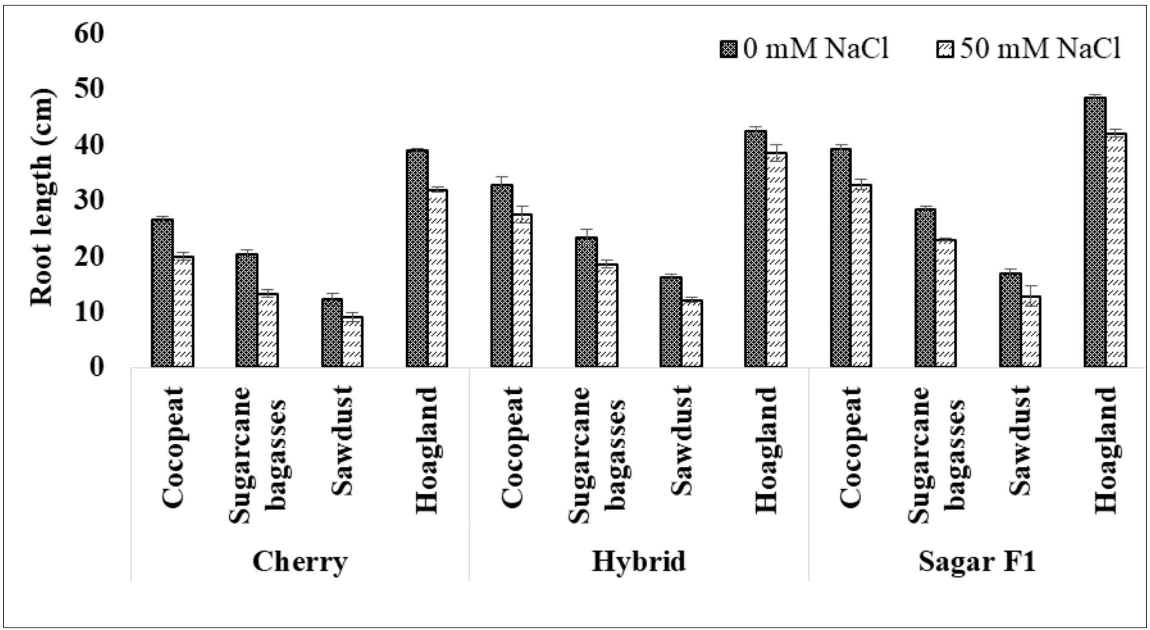


Fig. 2: Root length of tomato varieties under salt stress and different organic media

3.1.3. Shoot Fresh Weight

The analysis of variance (ANOVA) for the shoot fresh weight of tomato varieties grown in different organic media and salt stress is presented in Table 3 in which factors i.e., varieties, media and salt levels and their interactions i.e., varieties and media, varieties and salt were moderately significant and media and salt were significant except the interaction among varieties, media and salt. When compared to the hybrid and cherry types, the Sagar F1 variety had the highest value of shoot fresh weight in every growth media. The highest shoot fresh weight was observed in the Hoagland medium, followed by Cocopeat, while the lowest values was observed in the sawdust medium in the Sagar F1 variety. The sawdust medium yielded the lowest value of this parameter in the hybrid variety, whereas the Hoagland and Cocopeat media yielded the highest fresh weight. When compared to other varieties, the Cherry variety had the lowest shoot fresh weight in all growth media. Salt stress reduced shoot fresh weight in all growth media and across all types. The highest shoot fresh weight values under salt stress was noted in the Sagar F1 variety in the Hoagland medium, while the minimum shoot fresh weight value were reported under sawdust and sugarcane Bagasse media (Fig. 3).

Table 3: Analysis of variance (ANOVA) of shoot fresh weight of tomato varieties under salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	636.63	318.31	147.29	.0000 ***
Media (M)	3	12801.02	4267.00	1974.45	.0000 ***
Salt (S)	1	407.07	407.07	188.36	.0000 ***
V x M	6	52.43	8.73	4.04	.0023 **
V x S	2	29.52	14.76	6.83	.0025 **
M x S	3	26.66	8.88	4.11	.0112 *
V x M x S	6	13.80	2.30	1.06	.3968 ns
Error	48	103.73	2.16		
Total	71	14070.89			

***, **,* =0.001, 0.01, 0.05 level of significance, ns= level of non-significance

3.1.4. Root Fresh Weight

The analysis of variance (ANOVA) for the root fresh weight of tomato varieties in which media, varieties and salt level showed non-significant responses. The interaction between varieties and salt, varieties and media and media and salt were non-significant represented in table 4. In every growth media, the Sagar F1 variety had the highest value of root fresh weight when compared to the hybrid and cherry Varieties. The Hoagland medium produced the maximum root fresh weight, followed by Cocopeat, while the sawdust medium produced the lowest values in the Sagar F1 variety. In the hybrid variety, the sawdust medium produced the lowest fresh weight, while the Hoagland and Cocopeat media produced the greatest. The Cherry variety exhibited the lowest root fresh weight in all growing media as compared to other kinds. Salt stress reduced root fresh weight across all growing media and kinds. Under salt stress, the Sagar F1 variety in the Hoagland medium had the highest shoot fresh weight value, whereas sawdust and sugarcane Bagasse media had the lowest shoot fresh weight value (Fig. 4).

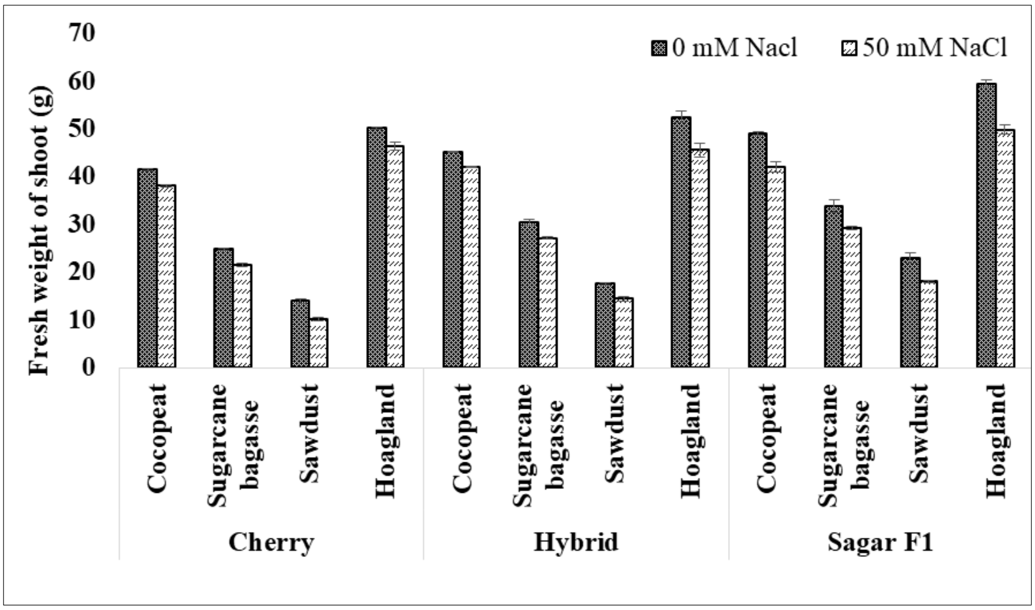


Fig. 3: Shoot fresh weight of tomato varieties under salt stress and different organic media

Table 4: Analysis of variance (ANOVA) of root fresh weight of tomato varieties under salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	58.30	29.15	287.52	.0000 ***
Media (M)	3	242.32	80.77	796.67	.0000 ***
Salt (S)	1	17.30	17.30	170.69	.0000 ***
V x M	6	0.59	0.09	0.97	.4536 ns
V x S	3	0.24	0.12	1.19	.3121 ns
M x S	2	0.37	0.12	1.22	.3108 ns
V x M x S	6	0.56	0.09	0.93	.4809 ns
Error	48	4.86	0.10		
Total	71	324.57			

*** =0.001 level of significance, ns= level of non-significance

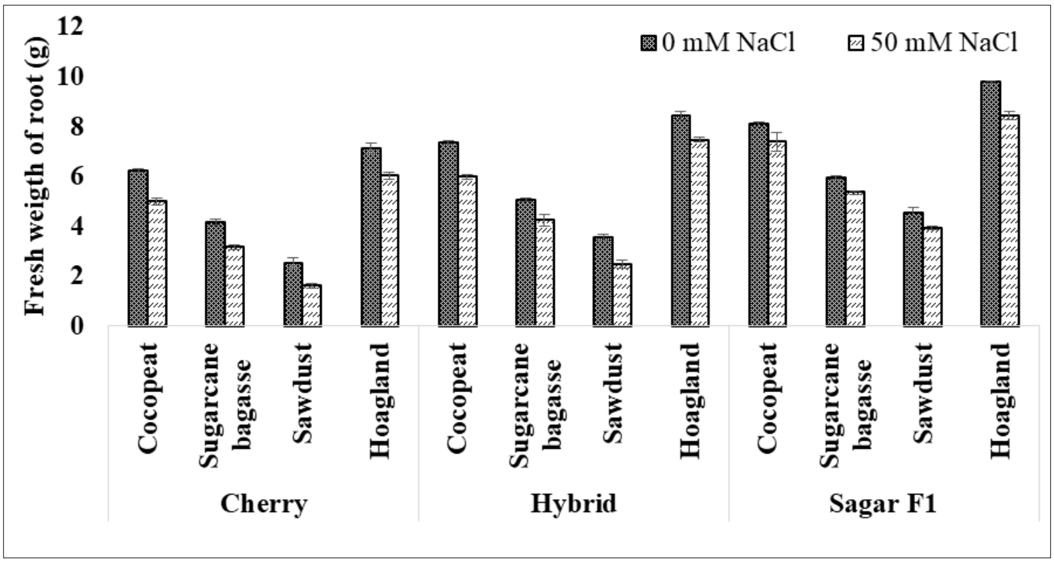


Fig. 4: Root fresh weight of tomato varieties under salt stress and different organic media

3.1.5. Shoot Dry Weight

Analysis of variance (ANOVA) showed that shoot dry weight of tomato varieties respond moderately significant. The interaction between varieties and media were moderately significant and others showed non-significant presented in table 5. The Hoagland in the Sagar F1 varieties showed highest value as compare to the Hoagland in remaining two varieties. The sawdust media in the Cherry tomato varieties showed lowest growth as compare Sagar and Hybrid tomato Varieties. Cherry cultivars have the lowest shoot dry weight values when compared to Hybrid and Sagar F1 types. In the table, Sagar F1 had the highest values. In all kinds, Hoagland and Cocopeat media recorded the highest shoot dry weight. Salt stress lowered shoot dry weight in all types of growth media. Under salt stress, the cherry variety had the lowest shoot dry weight in the sawdust medium, whereas the highest shoot dry weight was reported in the Hoagland and Cocopeat media (Fig. 5).

Table 5: Analysis of variance (ANOVA) of shoot dry weight of tomato varieties grown under different organic media under normal and salt stress

Source	df	SS	MS	F	P
Varieties (V)	2	6.25	3.12	46.03	.0000 ***
Media (M)	3	28.93	9.64	142.00	.0000 ***
Salt (S)	1	3.51	3.51	51.69	.0000 ***
V x M	6	1.41	0.23	3.47	.0063 **
V x S	2	0.27	0.135	1.98	.1481 ns
M x S	3	0.37	0.12	1.8.61	.1487 ns
V x M x S	6	0.25	0.042	0.63	.7034 ns
Error	48	3.26	0.067		
Total	71	44.27			

***, ** =0.001, 0.01 level of significance, ns= level of non-significance

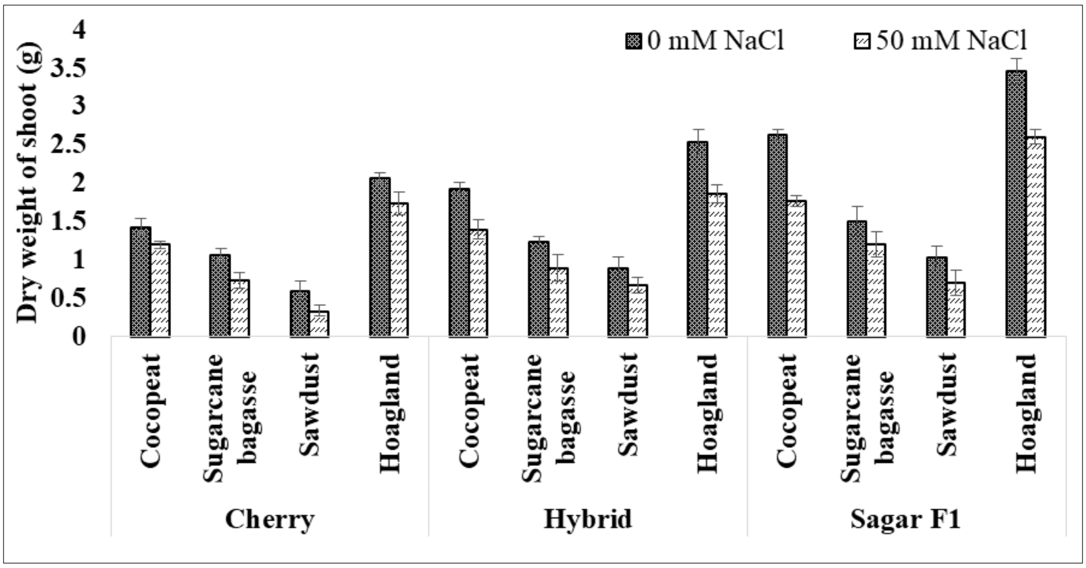


Fig. 5: Shoot dry weight of tomato varieties under salt stress and different organic media

3.1.6. Root Dry Weight

Analysis of variance (ANOVA) showed that root dry weight of tomato varieties, medias and salt. In which the interaction between varieties and media, varieties and salt and media and salt showed non-significant (Table 6). It was observed that in every growing media, the Sagar F1 variety had the highest value of root dry weight when compared to the hybrid and cherry types. The Hoagland medium produced the highest root dry weight, followed by Cocopeat, while the sawdust medium produced the lowest values in the Sagar F1 variety. In the hybrid variety, the sawdust medium produced the lowest dry weight, while the Hoagland and Cocopeat media produced the greatest. The Cherry variety exhibited the lowest root dry weight in all growing media as compared to other kinds. Salt stress reduced root dry weight across all growing media and kinds. Under salt stress, the Sagar F1 variety in the Hoagland medium had the highest shoot fresh weight value; whereas sawdust and sugarcane Bagasse media had the lowest shoot fresh weight value (Fig 6).

Table 6: Analysis of variance (ANOVA) of root dry weight of tomato varieties grown under organic media under normal and salt stress

Source	df	SS	MS	F	P
Varieties (V)	2	4.44	2.22	22.69	.0000 ***
Media (M)	3	16.21	5.40	55.18	.0000 ***
Salt (S)	1	2.06	2.06	21.11	.0000 ***
V x M	6	0.73	0.12	1.25	.2944 ns
V x S	2	0.0086	0.004	0.04	.9570 ns
M x S	3	0.060	0.020	0.206	.8916 ns
V x M x S	6	0.073	0.01	0.125	.9927 ns
Error	48	4.7	0.09		
Total	71	28.30			

*** =0.001 level of significance, ns= level of non-significance

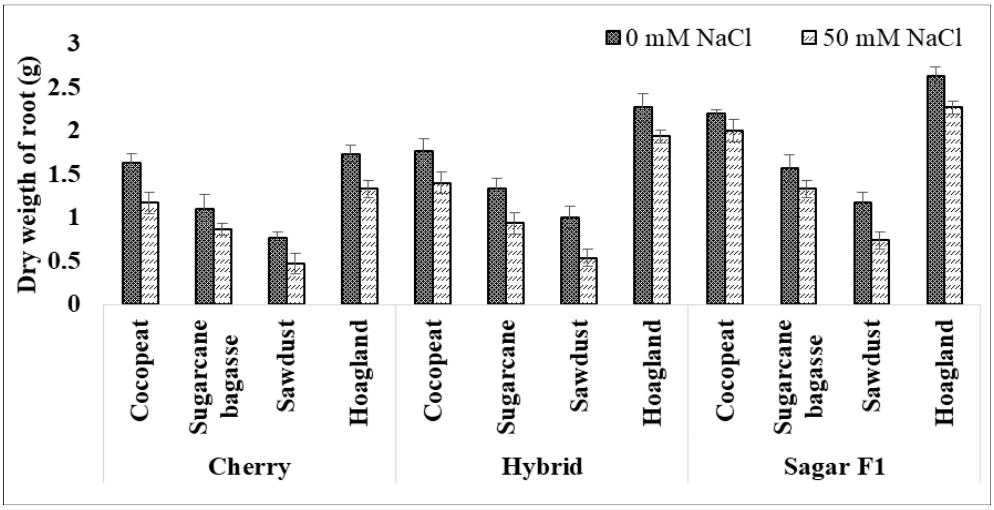
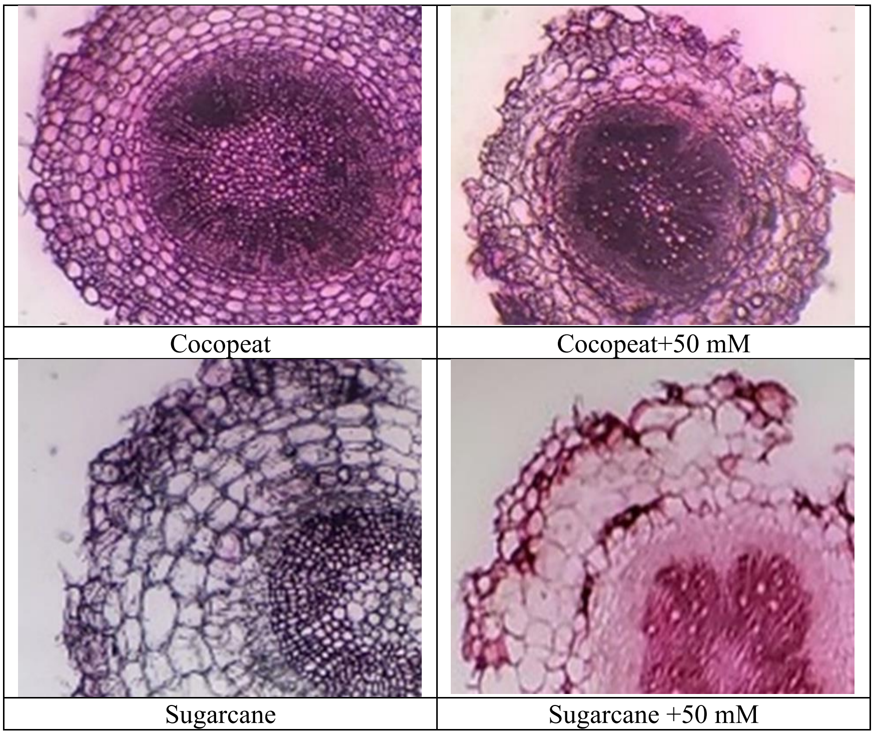


Fig. 6: Root dry weight of tomato varieties under salt stress and different organic media

3.2. Root Anatomical Characteristics

The root anatomical data was recorded from Fig 7 to 9.



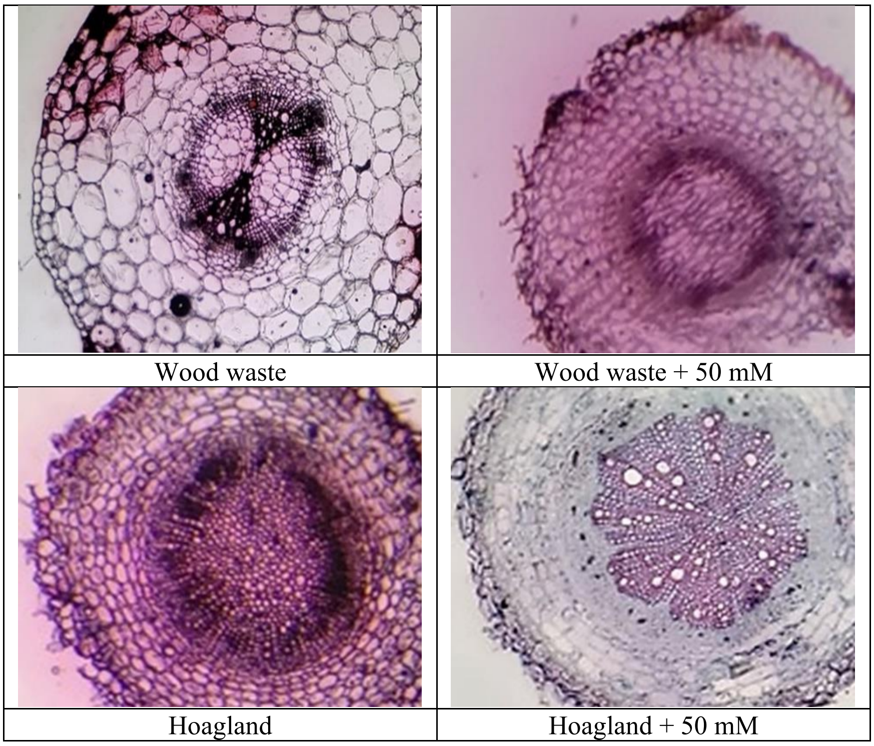
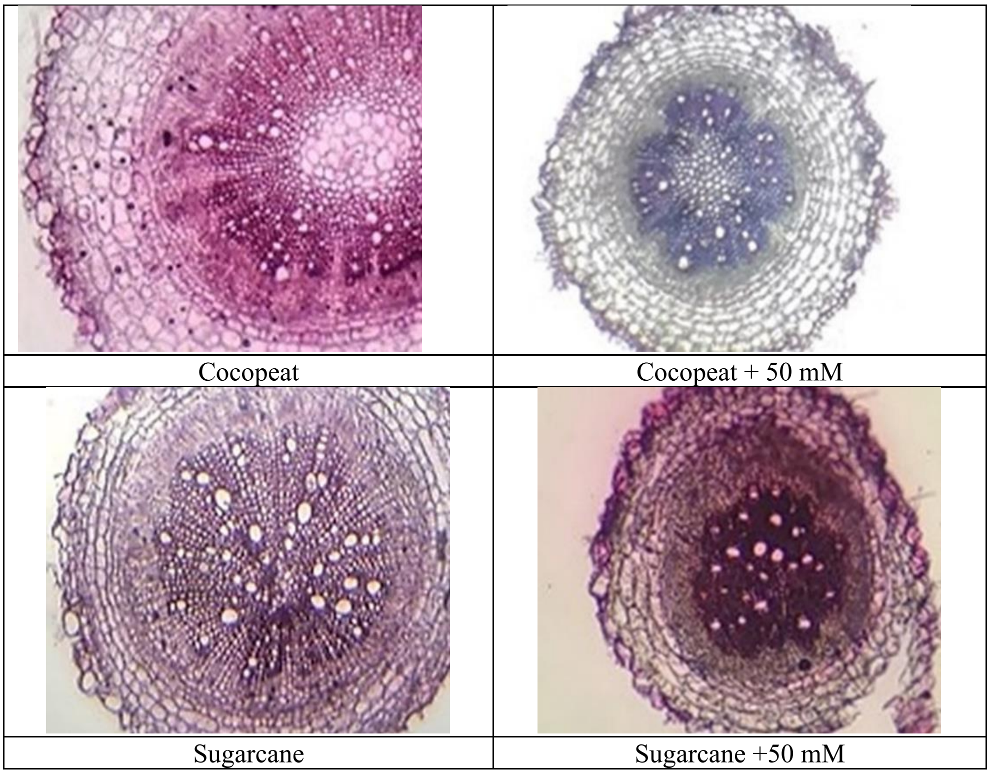
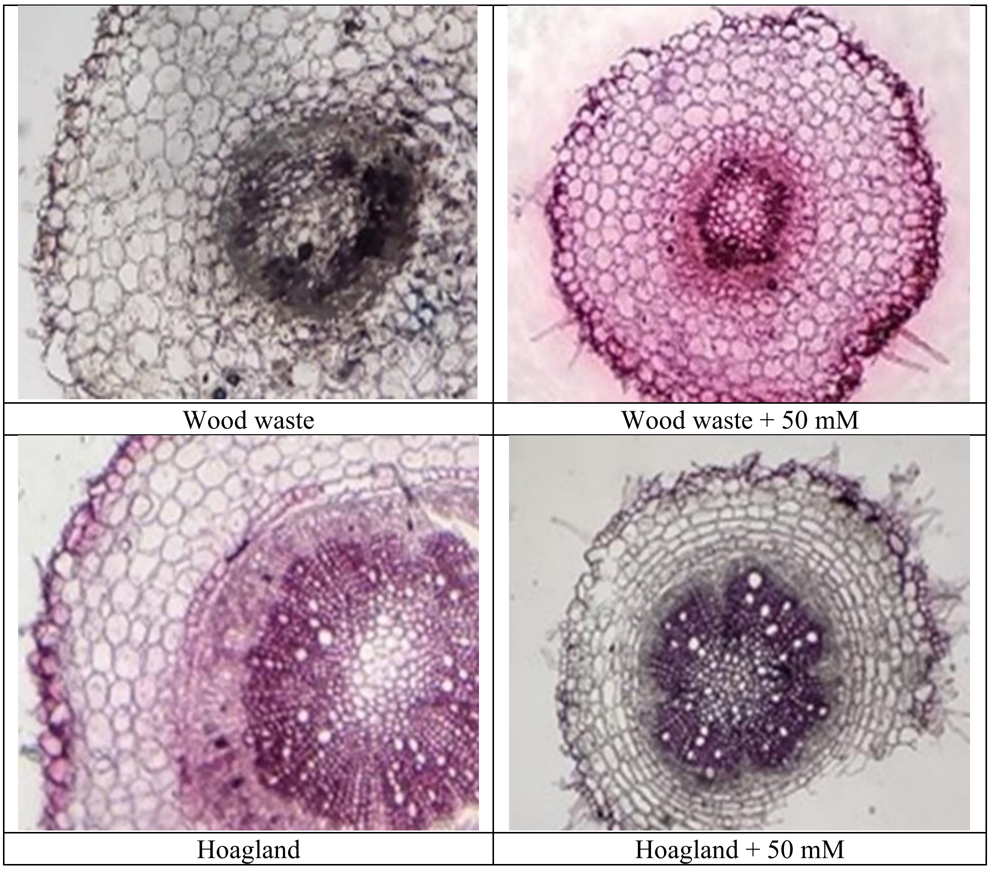


Fig. 7: Transverse sections of root of tomato variety (Cherry) grown in different organic media and salt stress

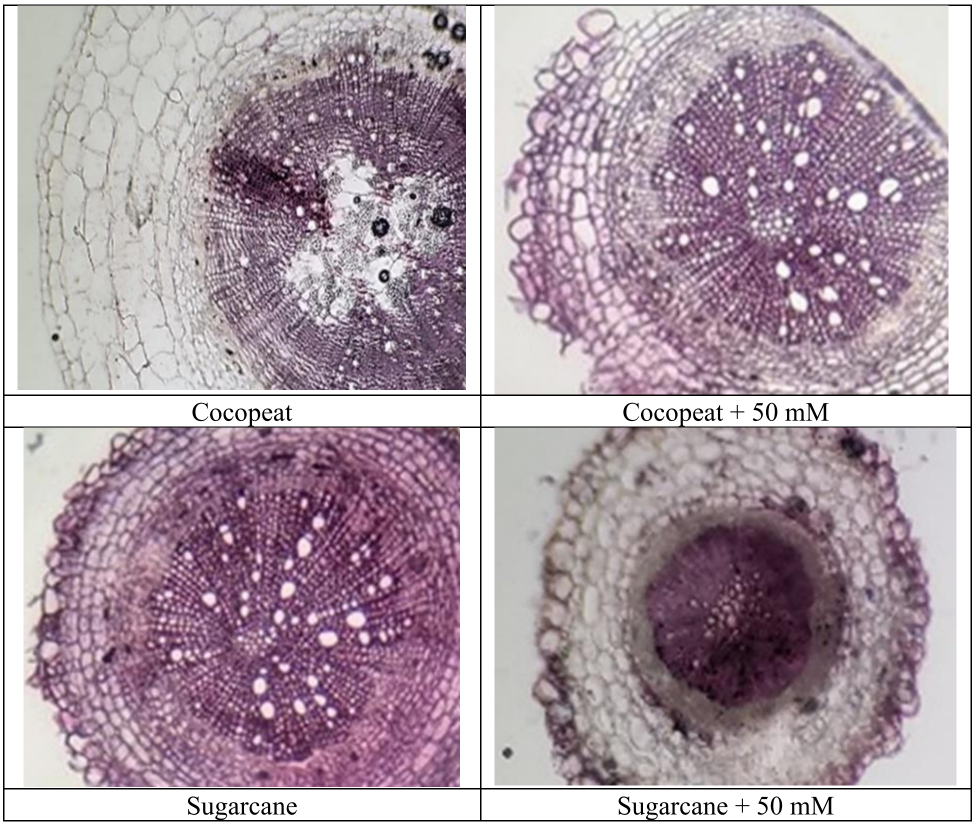




Wood waste | Wood waste + 50 mM

Hoagland | Hoagland + 50 mM

Fig. 8: Transverse sections of root of tomato variety (Hybrid) grown in different organic media and salt stress



Cocopeat | Cocopeat + 50 mM

Sugarcane | Sugarcane + 50 mM

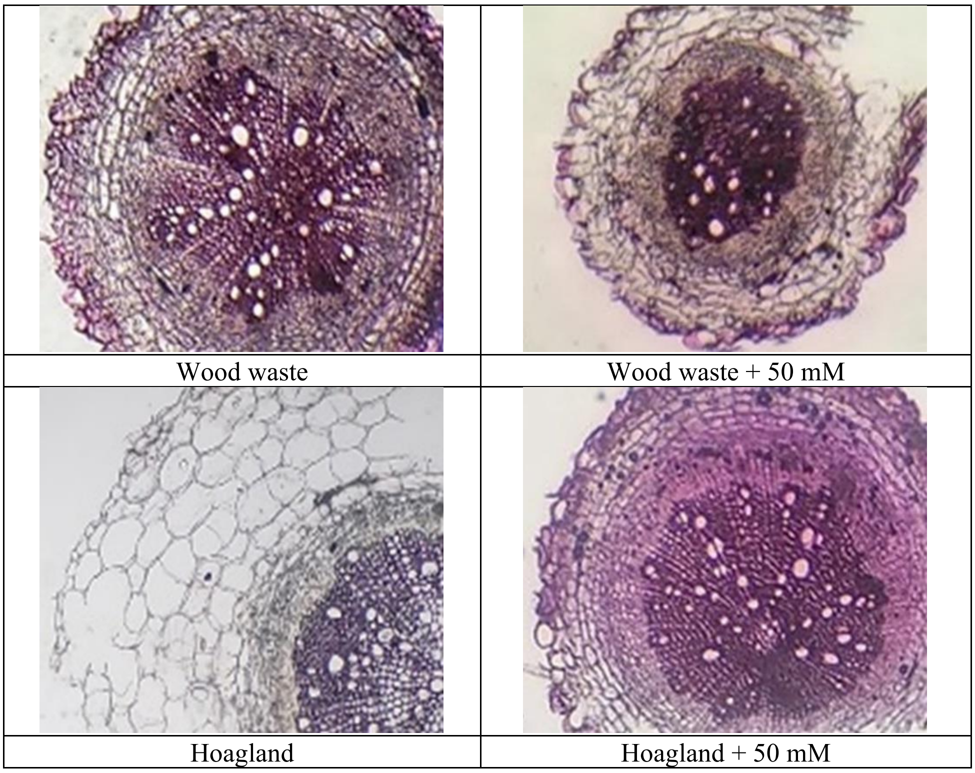


Fig. 9: Transverse sections of root of tomato variety (Sagar F1) grown in different organic media and salt stress

3.2.1. Root Cross Sectional Area

Analysis of variance (ANOVA) showed that cross sectional area of tomato varieties, interactions between varieties and media, varieties and salt and media and salt responds non-significant (Table 7). The Sagar F1 variety had the greatest root cross sectional area in every growing media, when compared to the hybrid and cherry varieties. In the sawdust medium, the shortest growth of cross sectional area was recorded. The Sagar F1 variety grew the most cross sectional area in the Hoagland medium, followed by Cocopeat. The Hoagland and Cocopeat media had the maximum cross sectional area while the sawdust medium had the lowest value of this parameter in the hybrid variety. In every growing media, the cherry variety had the smallest cross sectional area when compared to others. The salt stress reduced the cross sectional area in all growing media and types. The Hoagland and Cocopeat media had the highest cross sectional area. While the Sawdust and Sugarcane Bagasse was smallest (Fig.10).

3.2.2. Epidermis Thickness

The analysis of variance (ANOVA) for the epidermis thickness of root of tomato varieties which were grown in different organic media and salt stress is presented in table 8. The factors such as varieties, media, and salt levels, as well as their interactions such as varieties and media, varieties and salt, were highly significant, and the media and salt showed significantly. The highest value was noted in Hoagland media in Sagar F1 varieties. The moderate thickness was observed in the hybrid variety. The lowest thickness was observed in the Sawdust media in Cherry variety. The salt stress decreases the growth of tomato in all varieties. (Fig. 11)

Table 7: Analysis of variance (ANOVA) of root-cross-sectional area of tomato varieties under Salt stress and different organic media

Source	**df**	**SS**	**MS**	**F**	**P**
Varieties (V)	2	202947.89	101473.95	49.38	.0000 ***
Media (M)	3	726750.52	242250.17	117.896	.0000 ***
Salt (S)	1	79875.04	79875.045	38.872	.0000 ***
V x M	6	22087.17	3681.19	1.7915	.1208 ns
V x S	2	5389.57	2694.78	1.311	.2789 ns
M x S	3	4828.30	1609.43	0.7832	.5091 ns
V x M x S	6	4942.30	823.71	0.4008	.8748 ns
Error	48	98628.93	2054.76		
Total	71	1145449.745			

*** =0.001 level of significance, ns= level of non-significance

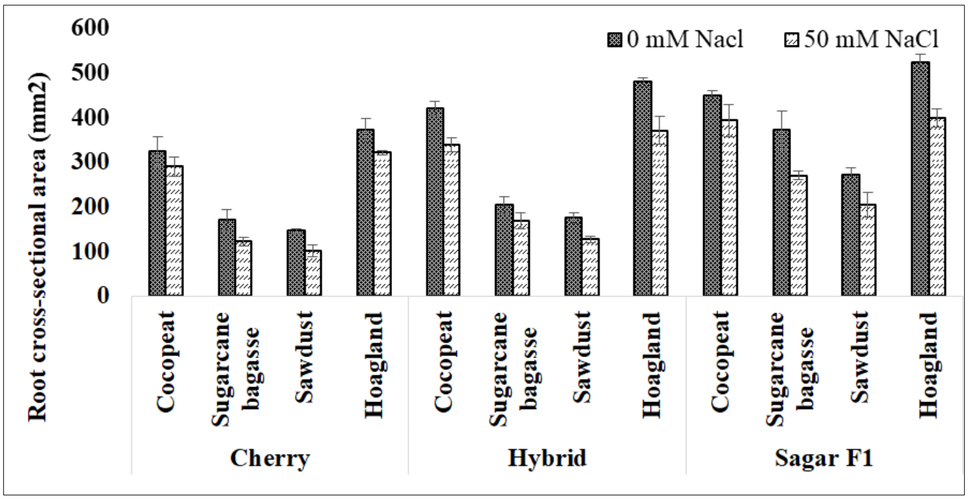


Fig. 10: Root-cross-sectional of tomato varieties under salt stress and different organic media

Table 8: Analysis of variance (ANOVA) of root epidermis thickness of tomato varieties under Salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	18475.69	9237.84	428.342	.0000 ***
Media (M)	3	88975.47	29658.49	1375.211	.0000 ***
Salt (S)	1	7285.85	7285.85	337.832	.0000 ***
V x M	6	3695.109	615.85	28.555	.0000 ***
V x S	2	635.229	317.614	14.727	.0000 ***
M x S	3	268.596	89.532	4.1514	.0108 *
V x M x S	6	1626.75	271.12	12.5716	.0000 ***
Error	48	1035.19	21.566		
Total	71	121997.91			

***, * =0.001, 0.05 level of significance

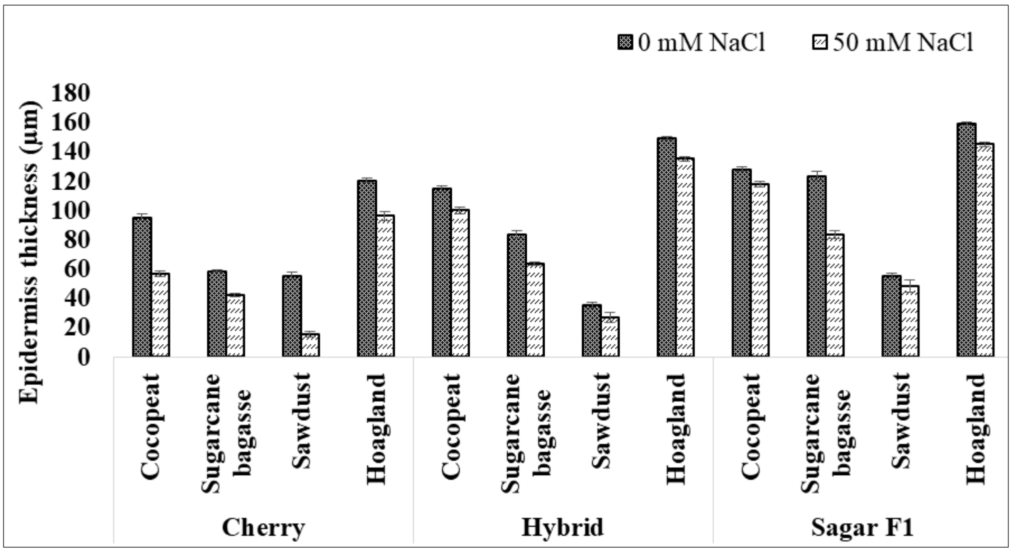


Fig. 11: Epidermis thickness of root of tomato varieties under salt stress and different organic media

3.2.4. Cortex Thickness

Analysis of variance (ANOVA) of cortex thickness of tomato varieties under salt stress and different organic media in which varieties and media respond to highly significant showed in table 9. The interaction between variety and media showed highly significant, interaction between variety and salt was non-significant and interaction between media and salt were respond significantly. The Hoagland and Cocopeat media showed maximum thickness in all varieties. While sawdust and Sugarcane Bagasse show minimum growth. Highest cortical thickness was show in Sagar F1 variety in Hoagland media. The salt stress reduce the cortical thickness of tomato in all varieties. The smallest value was observed in sawdust in cherry variety. (Fig. 12).

3.2.5. Cortical Cell Area

Analysis of variance (ANOVA) of cortical cell area of tomato varieties which grow under Salt stress and in different organic media. The interaction between variety and media showed significantly. And the interaction between varieties and salt and media and salt showed non-significant were (Table 10). In all varieties, the Hoagland and Cocopeat media had the highest cortical area. Sawdust and Sugarcane Bagasse had the smallest cortical area. In Hoagland media, the Sagar F1 type had the highest cortical cell area. In all tomato types, salt stress reduces the cortical cell area. Sawdust from the cherry variety had the lowest value. (Fig. 13).

Table 9: Analysis of variance (ANOVA) of root cortex thickness of tomato varieties under Salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	8299.426	4149.71	220.997	.0000 ***
Media (M)	3	32164.985	10721.66	570.9948	.0000 ***
Salt (S)	1	3763.070	3763.070	200.4067	.0000 ***
V x M	6	7787.71	1297.95	69.1240	.0000 ***
V x S	2	82.3381	41.1690	2.19250	.1227 ns
M x S	3	229.589	76.5299	4.07569	.0117 *
V x M x S	6	186.608	31.1014	4.07569	.1524 ns
Error	48	901.303	18.7771		
Total	71	53415.039			

***, * =0.001, 0.05 level of significance, ns= level of non-significance

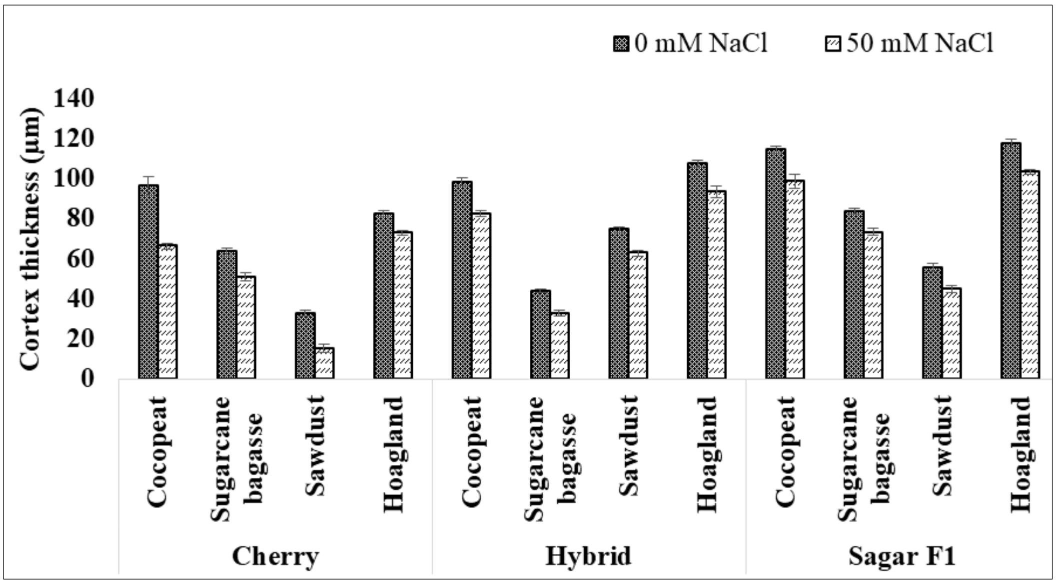


Fig. 12: Cortex thickness of roots of tomato varieties under salt stress and different organic media

Table 10: Analysis of variance (ANOVA) of root cortical cell area of tomato varieties under Salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	893364277	4.46682e8	88.992072	.0000 ***
Media (M)	3	3610248998	1.20342e9	239.755	.0000 ***
Salt (S)	1	130145426.1	1.30145e8	25.9287	.0000 ***
V x M	6	72287871.93	12047979	2.4003	.0415 *
V x S	2	10816652.86	5408326.4	1.0774	.3485 ns
M x S	3	6114404.058	2038134.7	0.4060	.7493 ns
V x M x S	6	29196253.41	4866042.2	0.9694	.4560 ns
Error	48	240928682.6	5019347.6		
Total	71	4993102566			

***, * =0.001, 0.05 level of significance, ns= level of non-significance

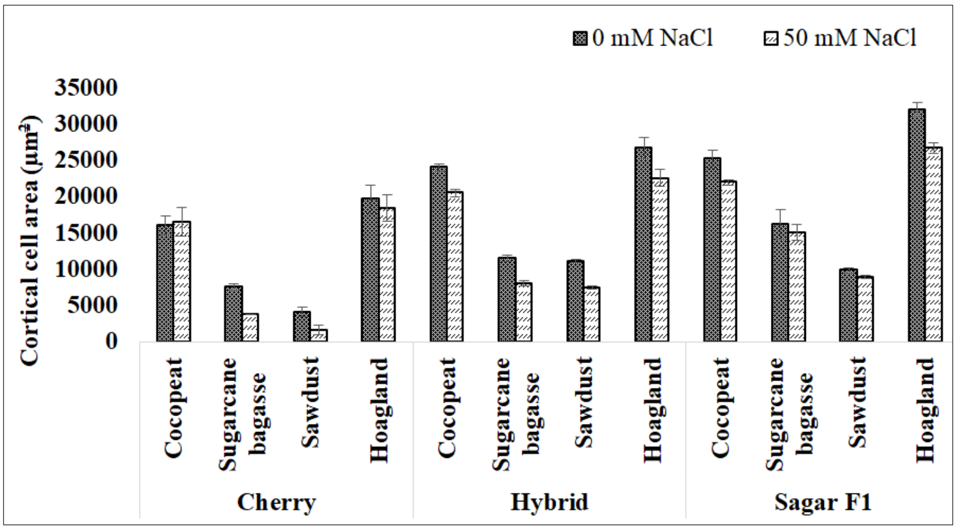


Fig. 13: Cortical cell area of root of tomato varieties under salt stress and different organic media

3.2.8. Vascular Bundle Thickness

Analysis of variance (ANOVA) showed that vascular bundle thickness the interaction between varieties and media and media and salt showed highly significant. While the interaction between varieties and salt were non-significant (Table 11). The highest growth was observed in Sawdust and Sugarcane Bagasse media. The smallest growth was recorded in Hoagland and Cocopeat media. The highest growth was recorded in Sagar F1 varieties while the lowest growth was in Cherry tomato variety (Fig. 14).

Table 11: Analysis of variance (ANOVA) vascular bundle thickness of roots of tomato varieties under Salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	18854.42	9427.212	898.312	.0000 ***
Media (M)	3	53122.85	17707.619	1687.34	.0000 ***
Salt (S)	1	4804.123	4804.123	457.78	.0000 ***
V x M	6	2067.145	344.524	32.82	.0000 ***
V x S	2	35.69381	17.8469	1.700	.1934 ns
M x S	3	241.7342	80.5780	7.67	.0003 ***
V x M x S	6	503.461	83.9102	7.99	.0000 ***
Error	48	503.728	10.494		
Total	71	80133.167			

*** =0.001 level of significance, ns= level of non-significance

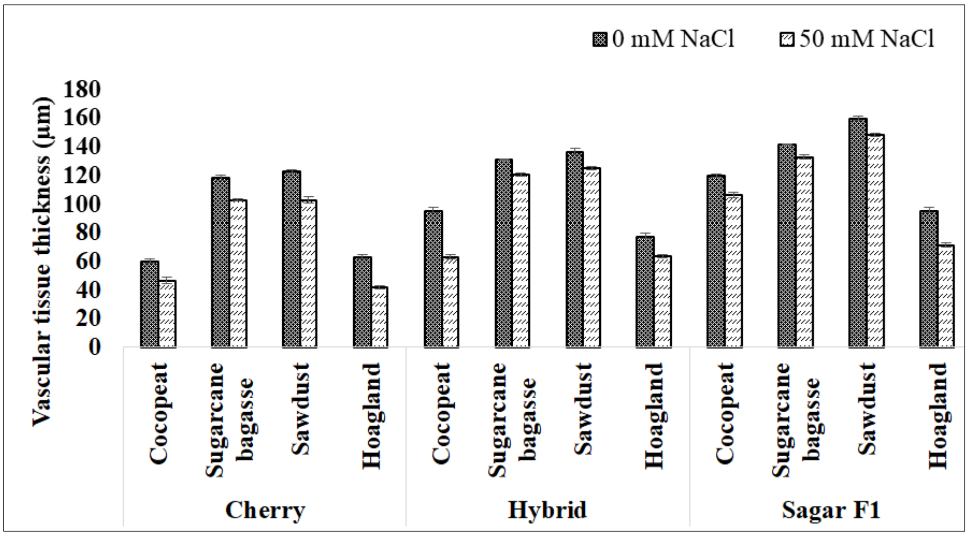


Fig. 14: Vascular bundle thickness of roots of tomato varieties under salt stress and different organic media

4.3. Stem Anatomical Characteristics

Stem anatomical data was recorded from Fig 15 to Fig 17

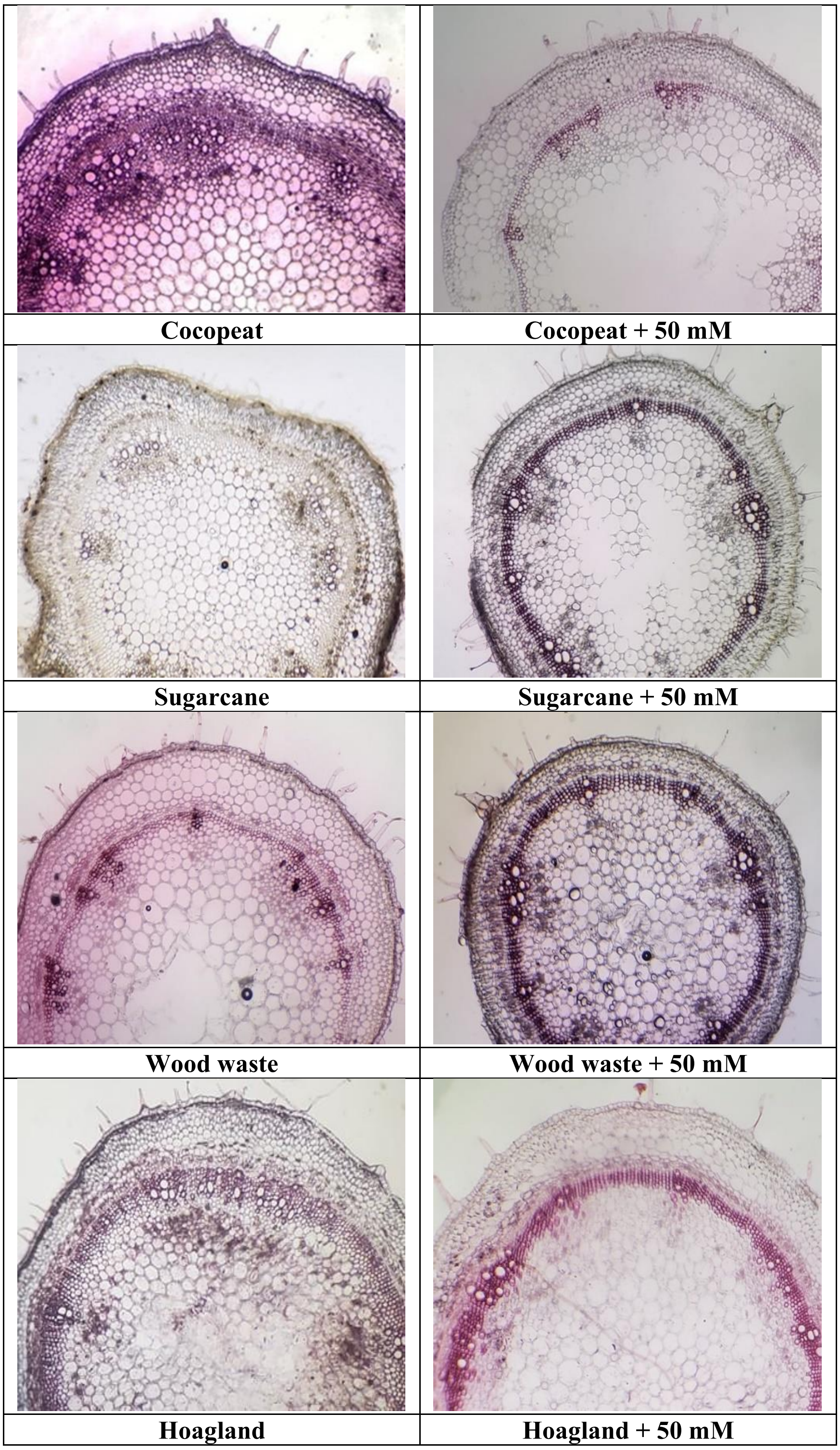


Fig. 15: Transverse sections of stem of tomato variety (Cherry) grown in different organic media and salt stress

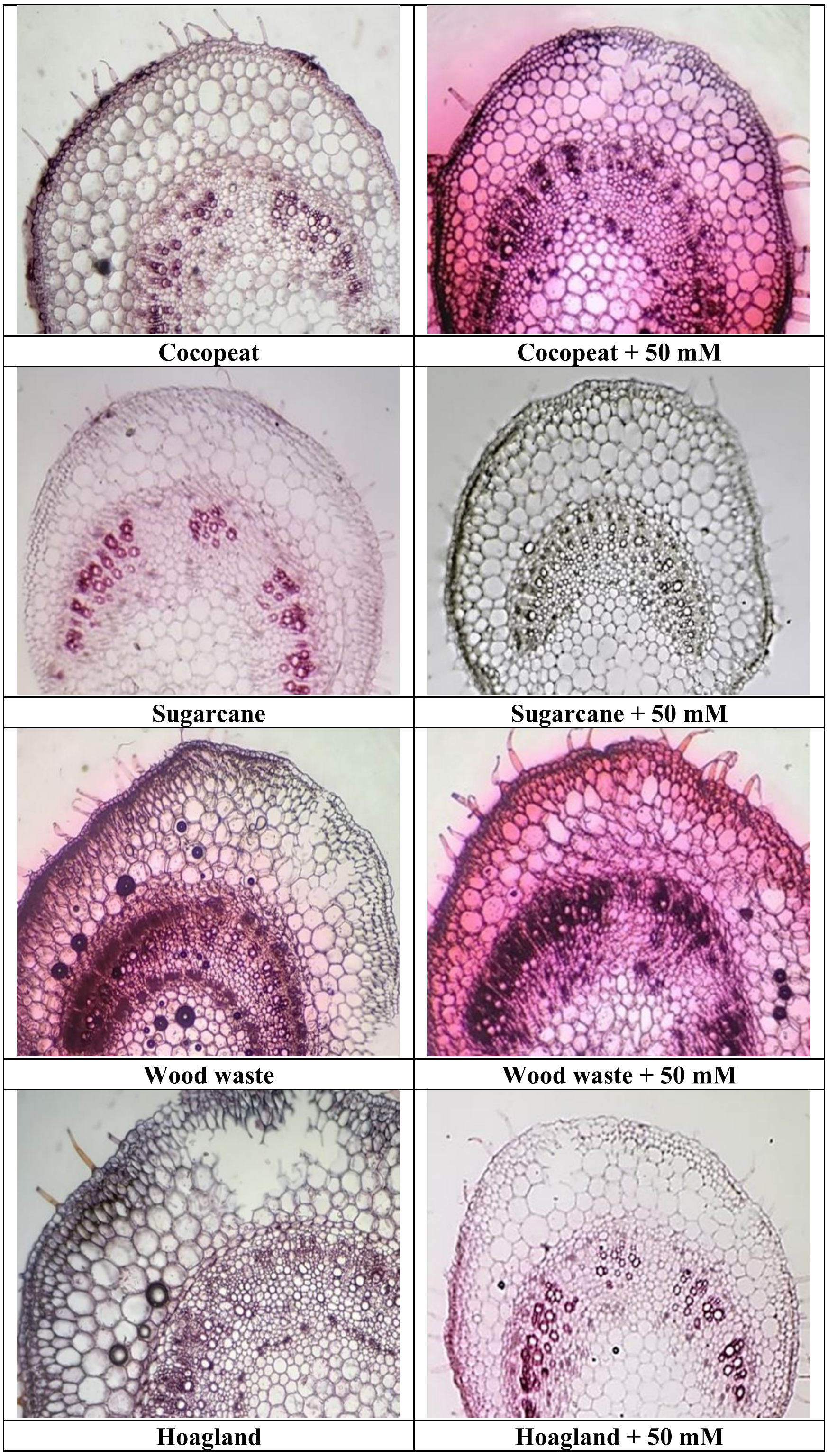


Fig. 16: Transverse sections of stem of tomato variety (Hybrid) grown in different organic media and salt stress

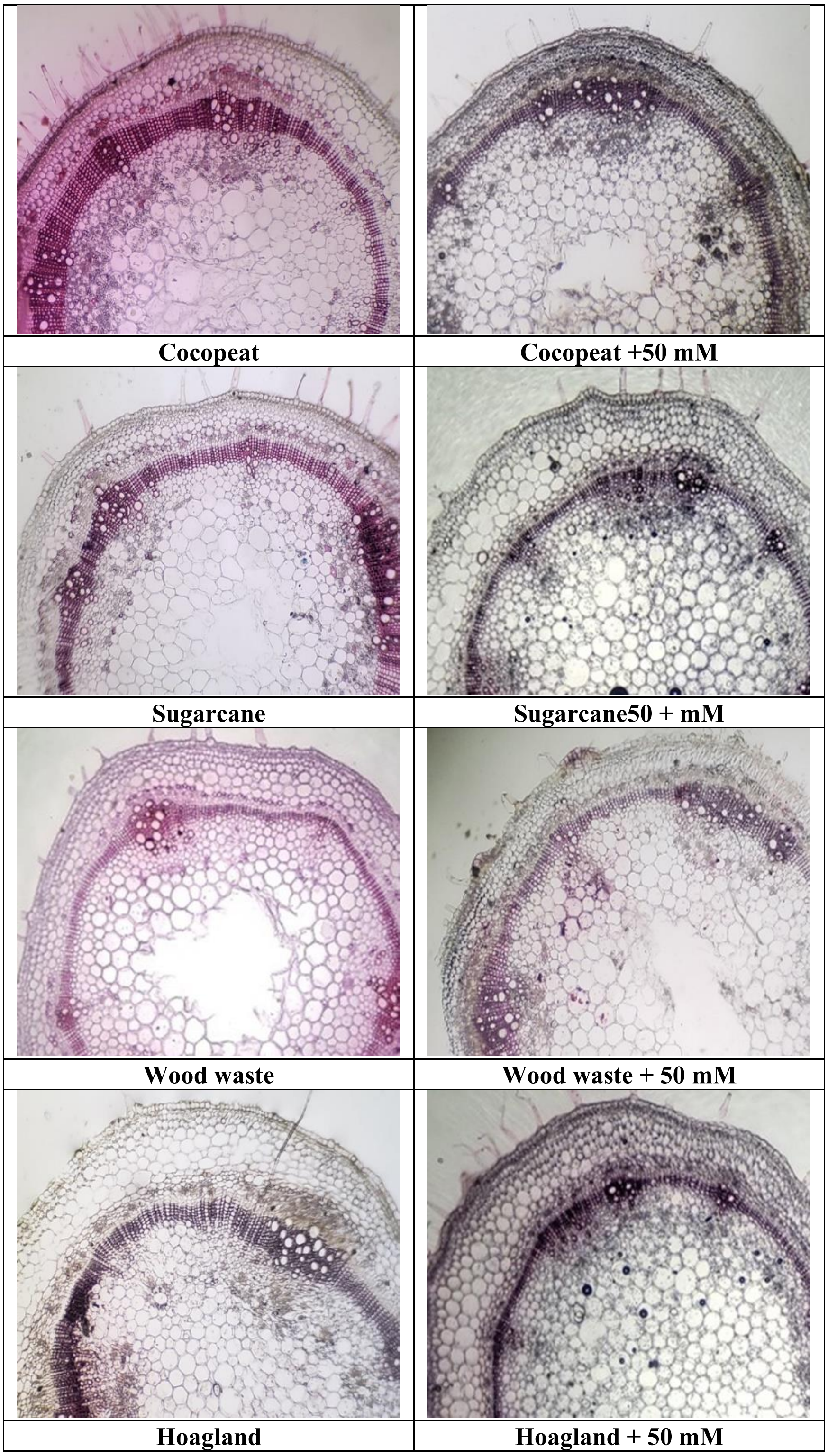


Fig. 17: Transverse sections of stem of tomato variety (Sagar F1) grown in different organic media and salt stress

3.3.1. Stem Cross Sectional Area

Analysis of variance (ANOVA) of shoot cross sectional area of tomato varieties under the salt stress and grown in different organic media. The interaction among varieties and media were significantly while the interaction between varieties and salt, and media and salt showed non-significant (Table 12). The Sagar F1 variety's Hoagland media grew the fastest. Cocopeat and Hoagland medium produced the most growth in all varieties. The lowest growth rates were seen in the Sawdust and Sugarcane Bagasse medium. The Sagar F1 tomato type grew the fastest, while the Cherry tomato variety grew the slowest. Growth was moderate in the Hybrid tomato variety. Salt stress reduces the cross sectional area of the stem in all tomato varieties. The cherry variant from Sawdust Media obtained the lowest value (Fig 18).

3.3.2. Epidermis Thickness

Analysis of variance (ANOVA) showed that epidermis thickness of tomato varieties which were grown in four organic media under salt stress. The interaction among varieties and media, varieties and salt and media and salt showed non-significant (Table 13). The Hoagland media in the Sagar F1 variety showed highest growth. The maximum growth in all varieties was in Cocopeat and Hoagland media. The minimum growths were recorded in the Sawdust and Sugarcane Bagasse media. The best growth was in Sagar F1 tomato variety and lowest growth was in Cherry tomato variety. Bus in Hybrid tomato variety the growth was moderate. Salt stress reduces the thickness of the epidermis in all tomato types. Sawdust media's cherry variety received the lowest value. (Fig. 19).

Table 12: Analysis of variance (ANOVA) of stem cross-sectional area of tomato varieties under salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	417846010.9	2.0892	39.4603	.0000 ***
Media (M)	3	929363779.8	3.09788	58.5112	.0000 ***
Salt (S)	1	60551930.85	60551931	11.43676	.0014 **
V x M	6	90994439.86	15165740	2.8644	.0182 *
V x S	2	4077244.692	2038622.3	0.38504	.6825 ns
M x S	3	2453275.077	817758.36	0.1544544	.9263 ns
V x M x S	6	12374999.75	2062500	0.3895553	.8821 ns
Error	48	254135937.7	5294498.7		
Total	71	1771797619			

***, **,* =0.001, 0.01, 0.05 level of significance, ns= level of non-significance

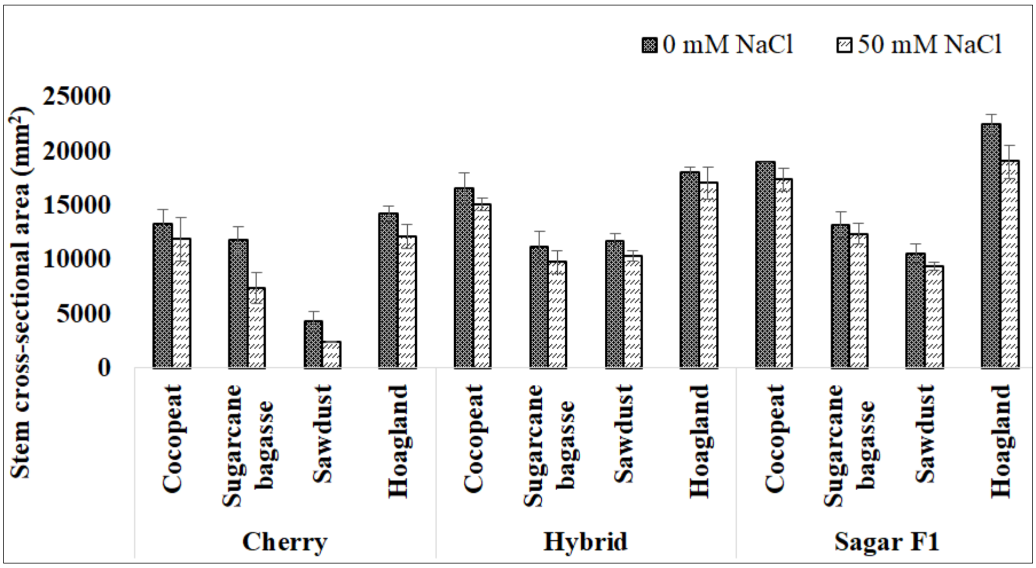


Fig. 18: Stem cross-sectional area of tomato varieties under salt stress and different organic media

Table 13: Analysis of variance (ANOVA) of stem epidermis thickness of tomato varieties under salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	279.8689	139.934	15.334	.0000 ***
Media (M)	3	2698.84	899.613	98.5844	.0000 ***
Salt (S)	1	180.911	180.9119	19.825	.0001 ***
V x M	6	52.3190	8.7198	0.955	.4651 ns
V x S	2	17.6378	8.81892	0.9664	.3877 ns
M x S	3	17.3619	5.7873	0.634	.5966 ns
V x M x S	6	27.9335	4.655	0.5101	.7976 ns
Error	48	438.0146	9.1253		
Total	71	3712.887			

*** =0.001 level of significance, ns= level of non-significance

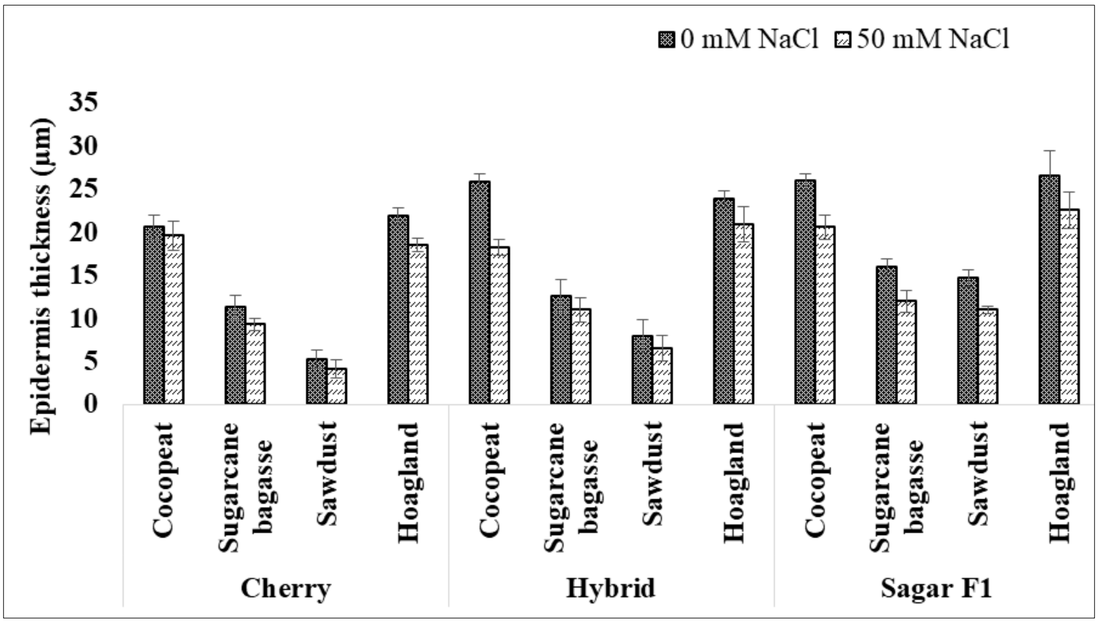


Fig. 19: Epidermis thickness of stem of tomato varieties under salt stress and different organic media

3.3.3. Cortical Cell Thickness

Analysis of variance (ANOVA) of Cortex thickness of tomato varieties which is grown in Salt stress and different organic media. The interaction between varieties and media shows highly significant and the interaction between varieties and salt and media and salt respond non-significantly (Table 14) The Sagar F1 variant of Hoagland media has the greatest thickness. Cocopeat and Hoagland media had the greatest thickness in all kinds. In the Sawdust and Sugarcane Bagasse media, the minimal thickness was measured. The Sagar F1 tomato type grew the fastest, while the Cherry tomato variety grew the slowest. Growth was moderate in the Hybrid tomato variety. Salt stress lowers cortical thickness in all tomato varieties. The cherry variant from Sawdust Media obtained the lowest value (Fig 20).

3.3.4. Cortical Cell Area

Analysis of variance (ANOVA) of cortical cell area of tomato varieties under Salt stress and different organic media in which varieties and media, varieties and salt and media and salt respond non-significant (Table 15). The upper cortical area is found in the Sagar F1 form of Hoagland media. In all types, Cocopeat and Hoagland media had the highest cortical area. The lowest cortical area was found in the Sawdust and Sugarcane Bagasse media. The Cherry tomato variety grew the slowest, while the Sagar F1 tomato variety grew the fastest. The growth rate of the Hybrid tomato cultivar was moderate. In all tomato types, salt stress reduces cortical area. Sawdust Media's cherry variation received the lowest value (Fig 21).

Table 14: Analysis of variance (ANOVA) of stem cortex thickness of tomato varieties under salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	28154.91	14077.46	25.0367	.0000 ***
Media (M)	3	142428.30	47476.10	84.4360	.0000 ***
Salt (S)	1	15387.25	15387.25	27.36618	.0000 ***
V x M	6	16914.15	2819.02	5.0136	.0005 ***
V x S	2	178.014	89.007	0.1582	.8540 ns
M x S	3	554.598	184.866	0.328	.8045 ns
V x M x S	6	1260.523	210.087	0.3736	.8921 ns
Error	48	26989.088	562.272		
Total	71	231866.86			

*** =0.001 level of significance, ns= level of non-significance

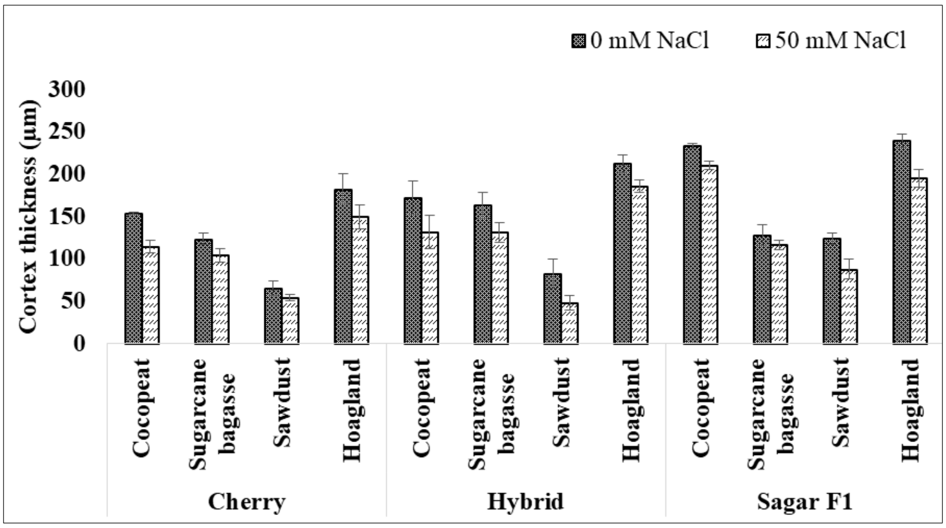


Fig. 20: Cortex thickness of stem of tomato varieties under salt stress and different organic media

Table 15: Analysis of variance (ANOVA) of stem cortical cell area of tomato varieties under salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	40841062.46	20420531	28.3938	.0000 ***
Media (M)	3	256391229.5	85463743	118.8334	.0000 ***
Salt (S)	1	18541225.97	18541226	25.7807	.0000 ***
V x M	6	9822285.84	1637047.6	2.2762	.0517 ns
V x S	2	1681191.805	840595.9	1.1688	.3194 ns
M x S	3	2017808.52	672602.84	0.93522	.4310 ns
V x M x S	6	1510389.248	251731.54	0.35002	.9064 ns
Error	48	34521088.71	719189.35		
Total	71	365326282.1			

*** =0.001 level of significance, ns= level of non-significance

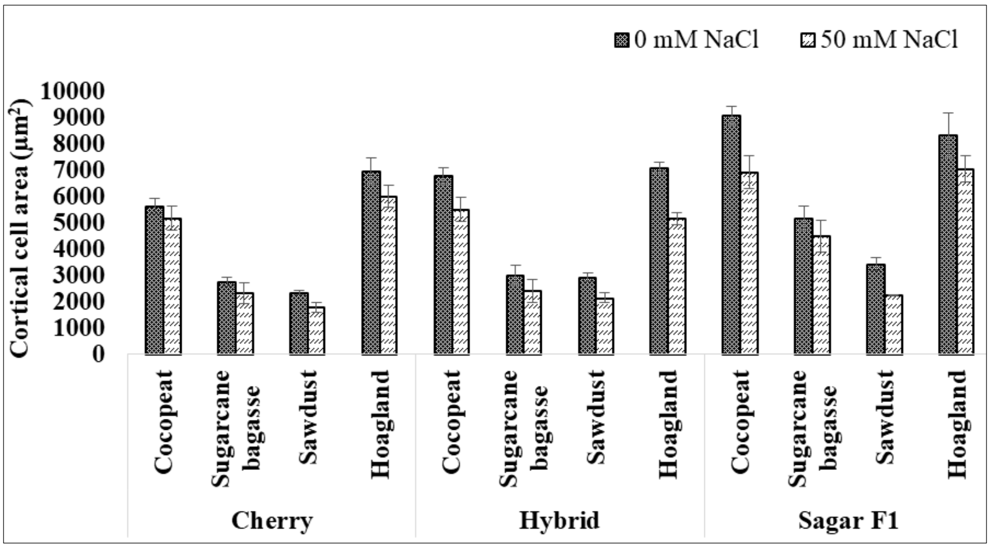


Fig. 21: Cortical cell area of stem of tomato varieties under salt stress and different organic media

3.3.5. Phloem Thickness

Analysis of variance (ANOVA) showed that Phloem thickness of tomato varieties, interactions between varieties and media showed highly significant while the interaction between varieties and salt and media and salt responds non-significant (Table 16). Sawdust and Sugarcane Bagasse medium produced the most growth. The least amount of growth was observed in Hoagland and Cocopeat media. The Sagar F1 types grew the fastest, while the Cherry tomato cultivars grew the slowest. The Hybrid tomato variety showed moderate growth (Fig. 22).

Table 16: Analysis of variance (ANOVA) of stem phloem thickness of tomato varieties under salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	7.677	3.8386	0.0439	.9570 ns
Media (M)	3	24577.4465	8192.48	93.7963	.0000 ***
Salt (S)	1	4811.559	4811.559	55.0878	.0000 ***
V x M	6	4105.978	684.3298	7.83493	.0000 ***
V x S	2	311.4554	155.727	1.7829	.1791 ns
M x S	3	584.9900	194.9966	2.2325	.0965 ns
V x M x S	6	454.0087	75.6681	0.8663	.5264 ns
Error	48	4192.4801	87.3433		
Total	71	39045.5969			

*** =0.001 level of significance, ns= level of non-significance

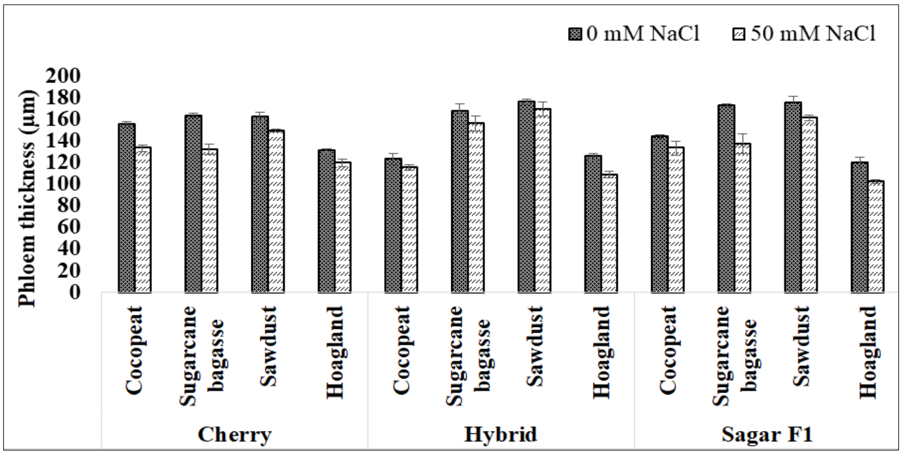


Fig. 22: Phloem thickness of stem of tomato varieties under salt stress and different organic media

3.4. Ions Analysis

3.4.1. Calcium Ions

Analysis of variance (ANOVA) of calcium ion of tomato varieties showed the interaction between varieties and media was highly significant, whereas the interaction between varieties and salt, as well as medium and salt, was not presented in table 17. Calcium ion concentrations were highest in cultivars grown under salt stress. The highest concentration of calcium ions was found in the Sagar F1 variant of Hoagland medium. While the Sagar F1 tomato type and the Hybrid tomato variety showed moderate amounts, the Cherry tomato variety showed the lowest level. When compared to normal, the salt stress metrics grew the most (Fig 23).

3.4.2. Sodium Ions

Analysis of variance (ANOVA) of sodium of ion analysis of tomato varieties under salt stress and grown in different organic media where the interaction between varieties and media was moderately significant but the interaction between varieties and salt, as well as media and salt, was non-significant (Table 18). The concentration of Sodium ion was highest in the varieties which was grow under salt stress. The maximum amount of sodium ions was present in Hoagland media in Sagar F1 variety. While the Hybrid tomato variety showed intermediate amount and Cherry tomato variety showed minimum amount as compare to Sagar F1 tomato variety and Hybrid tomato variety. The parameters of salt stress showed highest growth as compare to normal (Fig. 24).

Table 17: Analysis of variance (ANOVA) of calcium ions of tomato varieties under Salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	4844.7777	2422.38	324.789	.0000 ***
Media (M)	3	5393.375	1797.79	241.044	.0000 ***
Salt (S)	1	1730.680	1730.68	232.0465	.0000 ***
V x M	6	480.3333	80.055	10.7337	.0000 ***
V x S	2	41.444	20.722	2.7783	.0722 ns
M x S	3	13.4861	4.4953	0.6027	.6164 ns
V x M x S	6	129.222	21.5370	2.8876	.0175 *
Error	48	358	7.4583		
Total	71	12991.319			

***, * =0.001, 0.05 level of significance, ns= level of non-significance

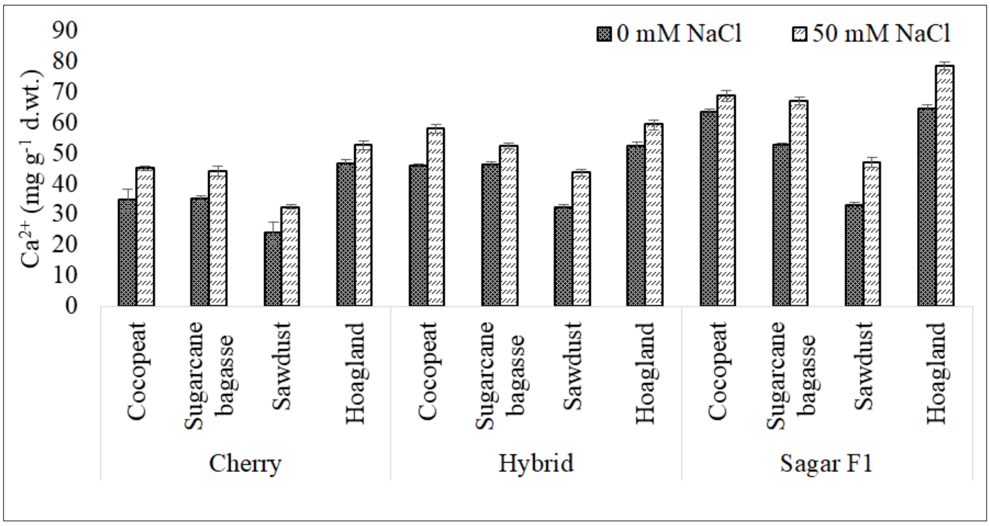


Fig. 23: Analysis of variance of calcium ions of tomato varieties under salt stress and different organic media

Table 18: Analysis of variance (ANOVA) of sodium ion of tomato varieties under salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	2255.25	1127.625	109.125	.0000 ***
Media (M)	3	9061.833	3020.611	292.317	.0000 ***
Salt (S)	1	1334.72	1334.72	129.1666	.0000 ***
V x M	6	228.75	38.125	3.6895	.0043 **
V x S	2	18.694	9.3472	0.9045	.4115 ns
M x S	3	56.5	18.833	1.8225	.1556 ns
V x M x S	6	27.75	4.625	0.4475	.8431 ns
Error	48	496	10.3333		
Total	71	13479.5			

***, ** = 0.001, 0.01 level of significance, ns= level of non-significance

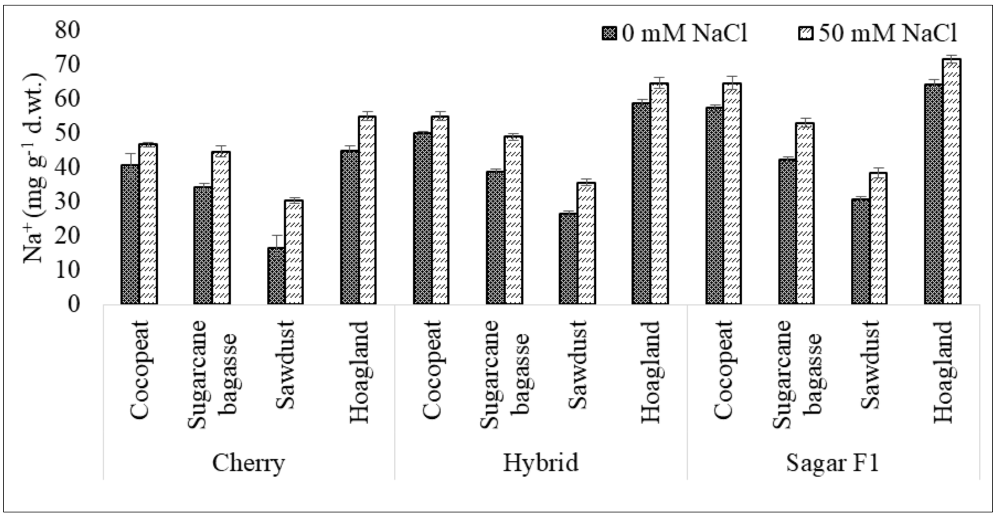


Fig. 24: Analysis of variance of sodium ions of tomato varieties under salt stress and different organic media

3.4.3. Potassium Ions

Analysis of variance (ANOVA) of Potassium of ion analysis of tomato varieties which is grown under salt stress and in different organic media. The interaction between varieties and media, and varieties and salt respond moderately significant and the interaction between media and salt respond non-significant (Table 19). The Sagar F1 variety of Hoagland media contained the most potassium ions. Cocopeat and Hoagland media contained the most potassium ions of any type. The Sawdust and Sugarcane Bagasse medium contained the least quantity of potassium ions. The Sagar F1 tomato type grew the fastest, while the Cherry tomato variety grew the slowest. The Hybrid tomato cultivar grew at a moderate rate. The cherry variety from Sawdust Media received the lowest value. The salt stress reduces the amount of Potassium ions in all varieties of tomato (Fig 25).

Table 19: Analysis of variance (ANOVA) of potassium ions of tomato varieties under salt stress and different organic media

Source	df	SS	MS	F	P
Varieties (V)	2	3384.36	1692.18	298.620	.0000 ***
Media (M)	3	8920.375	2973.45	524.727	.0000 ***
Salt (S)	1	946.125	946.125	166.963	.0000 ***
V x M	6	125.75	20.958	3.6985	.0042 **
V x S	2	64.5833	32.291	5.6985	.0060 **
M x S	3	32.930	10.976	1.937	.1362 ns
V x M x S	6	12.8611	2.1435	0.378	.8893 ns
Error	48	272	5.666		
Total	71	13758.98			

***, ** =0.001, 0.01 level of significance, ns= level of non-significance

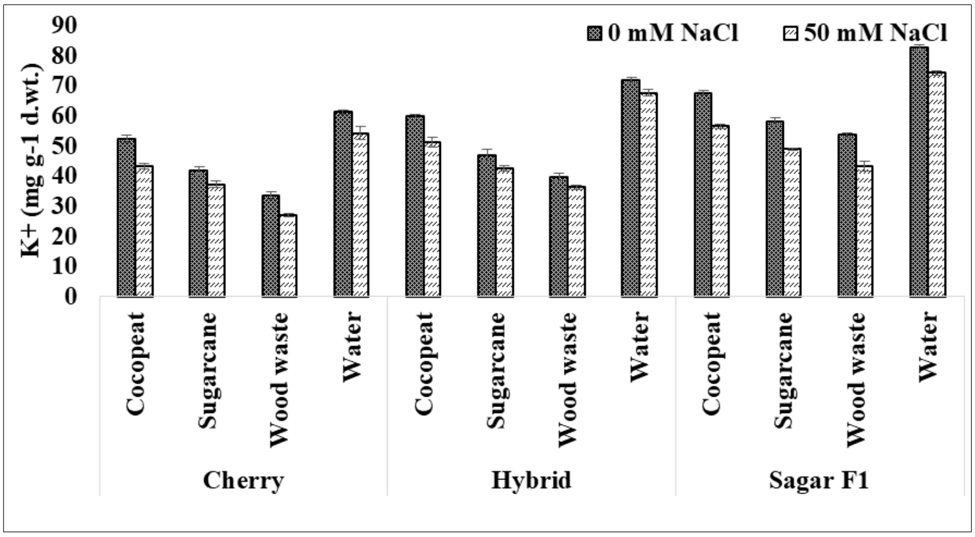


Fig. 25: Analysis of variance of potassium ions of tomato varieties under salt stress and different organic media

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