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ASSESSMENT OF MODERN SUGARCANE VARIETIES FOR ROOT CHARACTERISTICS UNDER HYDROPONIC CONDITION

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ABSTRACT:
Root system development is a key determinant of early seedling vigour, nutrient acquisition, water uptake and subsequent cane productivity in sugarcane. The present hydroponic study evaluated eight sugarcane varieties, namely Co 86032, CoM 0265, CoVSI 03102, VSI 08005, MS 10001, CoVSI 18121, PDN 15012 and PDN 13007, under controlled polyhouse conditions at Vasantdada Sugar Institute, Pune. Uniform one month old settlings were evaluated in a randomized complete block design with three replications up to the formative phase. Root length, shoot length and root:shoot length ratio were recorded at 60 and 90 days, while root cation exchange capacity (CEC) was estimated at 120 days. At 60 days, CoM 0265 recorded the highest root length (30.93 ± 3.31 cm), followed by MS 10001 (28.03 ± 2.83 cm). At 90 days, PDN 13007 (43.88 ± 3.01 cm), VSI 08005 (42.82 ± 10.67 cm) and MS 10001 (40.90 ± 3.75 cm) showed superior root elongation. VSI 08005 recorded the highest shoot length at 90 days (137.22 ± 15.08 cm), whereas CoVSI 03102 recorded the highest root CEC (126.67 ± 1.92 cmol(+) kg-1). The observed varietal differences demonstrate that this simple hydroponic approach can support easy and early screening of sugarcane genotypes for root vigour and root traits associated with drought adaptation.

KEYWORDS: Sugarcane; hydroponics; root length; shoot length; root:shoot length ratio; root cation exchange capacity; nutrient acquisition efficiency; drought screening.

INTRODUCTION

Sugarcane (Saccharum spp. hybrids) is a high-biomass C4 crop in which final cane yield depends on early establishment, tillering, stalk elongation, photosynthetic capacity and efficient uptake of water and nutrients (Smith et al., 2005; Inman-Bamber and Smith, 2005). The root system contributes directly to anchorage, nutrient absorption, water acquisition and whole-plant stress buffering (Smith et al., 2005). Therefore, root traits are increasingly considered useful supporting traits in breeding programmes, particularly for drought-prone and variable soil environments (Paez-Garcia et al., 2015; Wasaya et al., 2018).

Root growth is closely connected with yield because roots regulate the supply of water and mineral nutrients required for leaf expansion, photosynthesis, stalk elongation and biomass accumulation (Smith et al., 2005; Lynch, 1995). A more vigorous root system can increase the effective absorbing surface, improve nutrient acquisition, maintain leaf water status during transient stress and support better shoot growth (Lynch, 1995; Lynch, 2013). In sugarcane, early root vigour may also influence formative-phase growth and subsequent millable cane development (Smith et al., 2005; Inman-Bamber and Smith, 2005). Root length should be interpreted together with shoot vigour, root:shoot balance, physiological traits and field yield because the sugarcane root system supports water capture, nutrient uptake and biomass production that influence cane productivity (Smith et al., 2005; Inman-Bamber and Smith, 2005).

Hydroponic systems provide a useful method for observing roots without destructive soil excavation (Hoagland and Arnon, 1950; Resh, 2013). In such systems, genotypic differences in root elongation and root:shoot balance can be measured more easily and uniformly than under field soil conditions (Paez-Garcia et al., 2015; Wasaya et al., 2018). Hydroponics also helps reduce soil heterogeneity, which is useful for early-stage screening of breeding material (Resh, 2013; Paez-Garcia et al., 2015). However, hydroponic results must be treated as screening information, and promising varieties should be validated under field conditions (Paez-Garcia et al., 2015; Wasaya et al., 2018).

In India, sugarcane root-system studies have historically been linked with varietal performance, ratooning ability and adaptation to contrasting production environments (Shrivastava et al., 2000; Yadav et al., 2009). Early Indian sugarcane research at Coimbatore emphasized that the underground root system is important for understanding yield potential, while later IISR and coordinated research summaries reported that ratoon establishment depends first on stubble roots and subsequently on the development of new shoot roots, generally within the early formative period (Anonymous, 1949; Shrivastava et al., 2000). Therefore, root vigour, depth, root renewal and root:shoot balance are relevant supporting traits for Indian sugarcane breeding and management, especially under drought, waterlogging and ratoon-crop conditions (Inman-Bamber and Smith, 2005; Yadav et al., 2009). However, controlled root phenotyping in hydroponics is still less common than above-ground field evaluation; hence hydroponic root measurements should be integrated with field cane yield, stalk population, cane weight and juice quality before recommending a variety, because sugarcane root-system

function is connected with water uptake, nutrient acquisition and cane productivity (Smith et al., 2005; Inman-Bamber and Smith, 2005).
The present study was undertaken to assess varietal variation in root growth, shoot growth, root:shoot length ratio and root cation exchange capacity of eight sugarcane varieties under hydroponic conditions up to the formative phase.

2. MATERIALS AND METHODS

2.1 Experimental site

The experiment was carried out in the polyhouse under controlled conditions at the Plant Breeding Section, Vasantdada Sugar Institute (VSI), Manjari Budruk, Pune, Maharashtra, India. The study was conducted as a hydroponic root growth experiment up to the formative phase of sugarcane.

2.2 Plant material

Eight sugarcane varieties were used: Co 86032, CoM 0265, CoVSI 03102, VSI 08005, MS 10001, CoVSI 18121, PDN 15012 and PDN 13007. Uniform one-month-old healthy seedlings raised from sugarcane setts were selected for transfer to the hydroponic jars.

2.3 Hydroponic setup

Selected seedlings were placed in hydroponic nutrient solution in wide mouth glass jars of approximately 5 L capacity with dimensions of 30 cm height x 15 cm length x 12 cm width (Hoagland and Arnon, 1950; Resh, 2013). The seedlings were supported by a plastic frame so that the root zone remained immersed in solution while the shoot remained above the jar opening (Resh, 2013). The external surface of each jar was covered with black plastic film to block light penetration into the nutrient solution and to reduce algal and fungal growth (Resh, 2013). The nutrient solution was monitored and maintained regularly during the experiment (Hoagland and Arnon, 1950; Resh, 2013).

2.4 Experimental design

The experiment was laid out in a randomized complete block design (RCBD) with eight varieties and three replications (Gomez and Gomez, 1984). Each replicated hydroponic jar was treated as an experimental unit for recording observations.

2.5 Observations recorded

Root length and shoot length were recorded in centimetres at 60 and 90 days (Paez-Garcia et al., 2015; Wasaya et al., 2018). Root:shoot length ratio was calculated as root length divided by shoot length for each replicate (Paez-Garcia et al., 2015; Wasaya et al., 2018). Root cation exchange capacity (CEC) was estimated at 120 days (Heintze, 1961; Chapman, 1965).

2.6 Statistical analysis

The data were summarized as mean, standard deviation (SD) and standard error (SE) of three replications (Gomez and Gomez, 1984). One-way ANOVA was calculated to estimate the varietal effect for root length, shoot length and root:shoot ratio following standard agricultural statistical procedures (Gomez and Gomez, 1984).

2.7 Root cation exchange capacity- Root cation exchange capacity (CEC) was determined using a modified Hydrogen Saturation–Ammonium Acetate (NH_4OAc) Exchange Method (Heintze, 1961; Chapman, 1965).

2.8 Preparation and maintenance of Hoagland’s nutrient solution

The modified Hoagland’s nutrient solution was prepared as per the composition given in Table 1. The required quantities of macronutrients, namely potassium nitrate, calcium nitrate, potassium dihydrogen phosphate and magnesium sulphate, were dissolved in water on a g L^{-1} basis. The micronutrients, including the iron source, were added as per the quantities given for g 250 L^{-1}. The nutrient solution was thoroughly mixed before use and filled in the hydroponic containers. The solution was replaced at weekly intervals to maintain nutrient availability and avoid microbial contamination. Continuous oxygen supply was provided to the Hoagland’s medium using a small aquarium type air pump, similar to those used in fish tanks, with an air tube placed inside the nutrient solution. This aeration helped maintain dissolved oxygen in the root zone and supported healthy root growth under hydroponic conditions. Modified Hoagland’s nutrient medium was used for sugarcane hydroponic studies as described by Hari et al. (2017).

Table 1. Composition of modified Hoagland's nutrient solution

Sl. No.	Ingredient	Quantity	Unit
Macronutrients			
1	Potassium nitrate	0.608	g L-1
2	Calcium nitrate	1.416	g L-1
3	Potassium dihydrogen phosphate	0.164	g L-1
4	Magnesium sulphate	0.560	g L-1
Micronutrients			
5	EDTA-ferric monosodium salt	6.00	g 250 L-1
6	Boric acid	1.43	g 250 L-1
7	Manganese chloride tetrahydrate	0.91	g 250 L-1

8	Zinc sulphate	0.11	g 250 L-1
9	Cupric sulphate	0.04	g 250 L-1
10	Molybdic acid	0.01	g 250 L-1

Hari, K., Vasantha, S., Anna Durai, A., Rajeshkumar, Brinda, C., & Shruthi, P. (2017).

3. Experimental setup

Figure 1. Hydroponic sugarcane root growth screening trial under polyhouse conditions

Figure 2. Representative root system of a sugarcane seedling (CoVSI 03102) grown under hydroponic conditions.

4. RESULTS

4.1 Root and shoot growth at 60 and 90 days

Clear varietal differences were observed in root length and shoot length at both observation stages. At 60 days, CoM 0265 recorded the highest mean root length, followed by MS 10001 and CoVSI 18121. At 90 days, PDN 13007, VSI 08005 and MS 10001 recorded the highest root lengths, indicating stronger root elongation during the later formative phase. Shoot length at 90 days was highest in VSI 08005, followed by MS 10001 and Co 86032.

Table 2. Root and shoot growth of sugarcane varieties under hydroponics.

Values are mean ± SE (n = 3).

Variety	Root length 60 d (cm)	Root length 90 d (cm)	Shoot length 60 d (cm)	Shoot length 90 d (cm)
Co 86032	18.60 ± 1.74	24.53 ± 2.77	76.65 ± 6.64	117.30 ± 3.52
CoM 0265	30.93 ± 3.31	37.50 ± 3.31	73.30 ± 10.94	83.92 ± 12.49
CoVSI 03102	19.82 ± 3.30	30.70 ± 3.92	78.05 ± 6.56	110.02 ± 4.08
VSI 08005	23.15 ± 0.29	42.82 ± 10.67	93.80 ± 9.72	137.22 ± 15.08
MS 10001	28.03 ± 2.83	40.90 ± 3.75	85.67 ± 17.81	119.77 ± 1.47
CoVSI 18121	25.20 ± 4.75	33.55 ± 3.34	85.77 ± 6.99	93.38 ± 15.08
PDN 15012	16.95 ± 1.72	32.60 ± 5.47	49.13 ± 4.66	84.62 ± 15.62
PDN 13007	23.67 ± 0.64	43.88 ± 3.01	84.78 ± 5.45	114.12 ± 12.24

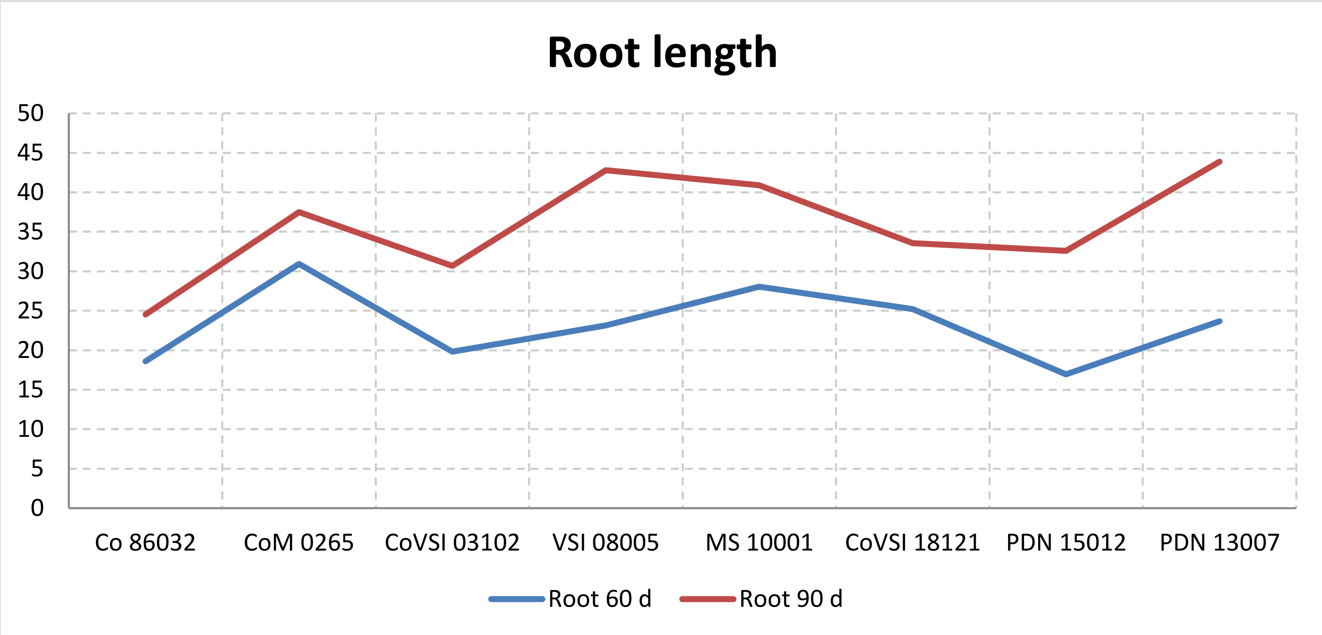

Figure 3. Root length of sugarcane varieties at 60 and 90 days.

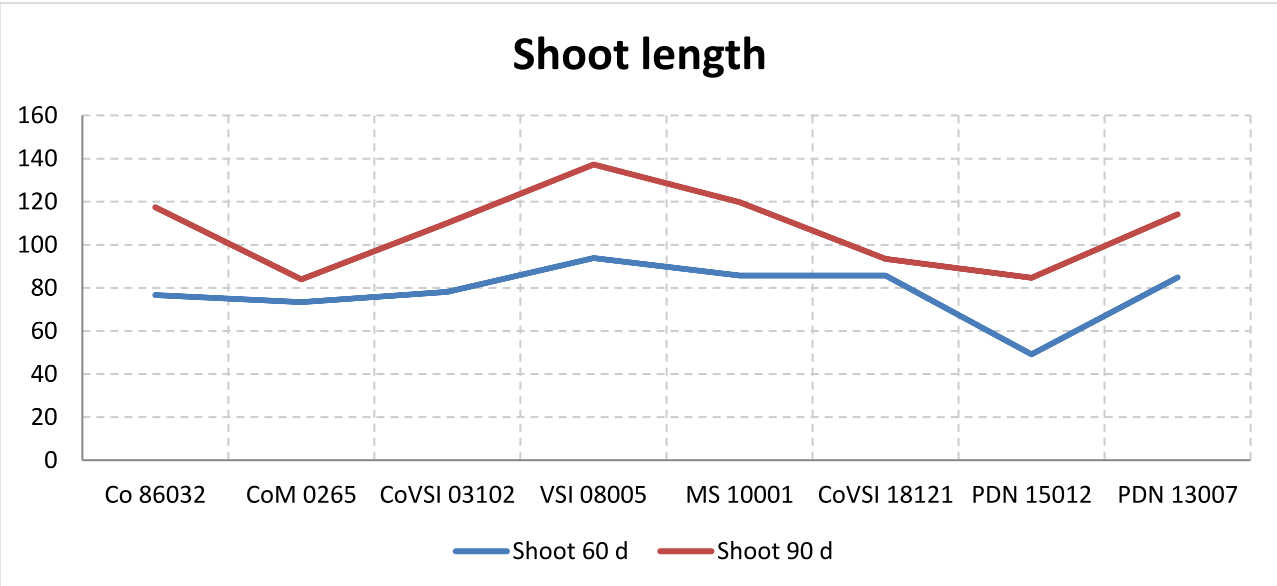

Figure 4. Shoot length of sugarcane varieties at 60 and 90 days.

4.2 Root:shoot length ratio

Root:shoot length ratio provides an indication of the proportional balance between below-ground and above-ground elongation (Lynch, 1995; Paez-Garcia et al., 2015). CoM 0265 recorded the highest root:shoot length ratio at both stages, suggesting proportionally greater root elongation relative to shoot length. At 90 days, PDN 15012, PDN 13007 and CoVSI 18121 also maintained comparatively high root:shoot length ratios.

Table 3. Root:shoot length ratio and growth gain from 60 to 90 days.

R:S = root length/shoot length; values are mean ± SE for the root:shoot length ratio (n = 3).

Variety	R:S 60 d	R:S 90 d	Root gain (cm)	Shoot gain (cm)
Co 86032	0.24 ± 0.01	0.21 ± 0.03	5.93	40.65
CoM 0265	0.43 ± 0.03	0.46 ± 0.04	6.57	10.62
CoVSI 03102	0.25 ± 0.02	0.28 ± 0.03	10.88	31.97
VSI 08005	0.25 ± 0.03	0.30 ± 0.04	19.67	43.42
MS 10001	0.34 ± 0.04	0.34 ± 0.03	12.87	34.10
CoVSI 18121	0.29 ± 0.04	0.38 ± 0.07	8.35	7.62
PDN 15012	0.34 ± 0.00	0.39 ± 0.04	15.65	35.48
PDN 13007	0.28 ± 0.03	0.39 ± 0.02	20.22	29.33

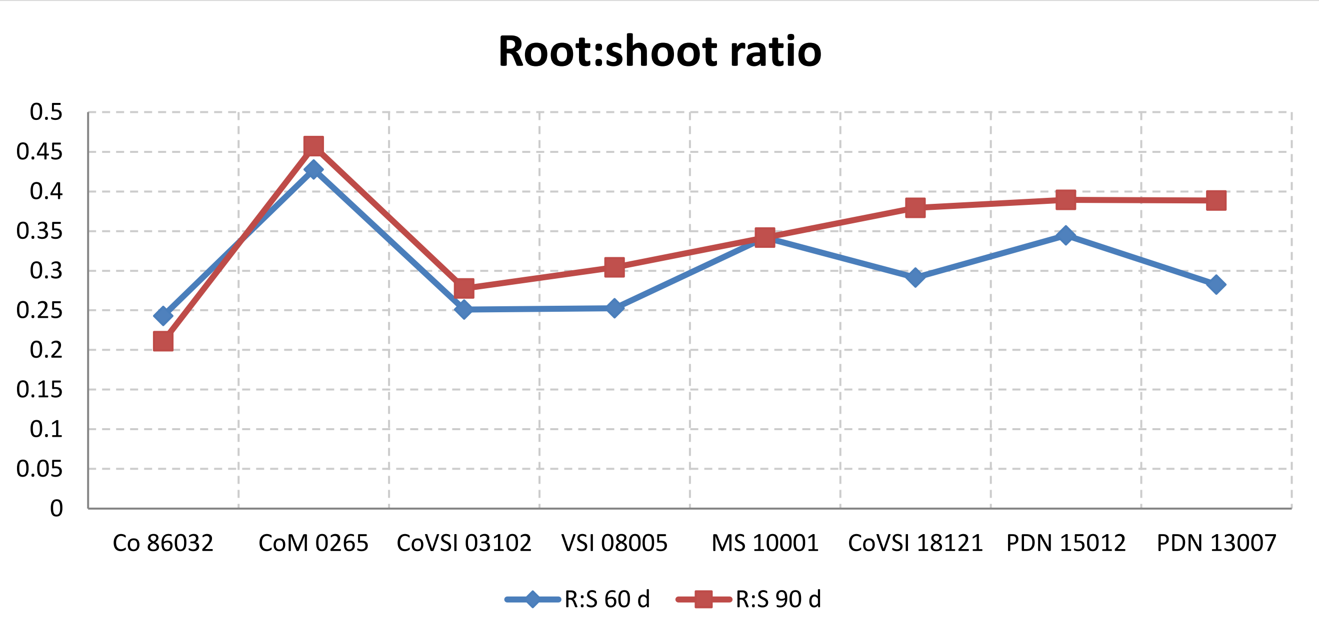

Figure 5. Root:shoot length ratio of sugarcane varieties at 60 and 90 days.

4.3 Root cation exchange capacity at 120 days

Root CEC differed among varieties at 120 days. CoVSI 03102 recorded the highest CEC, followed by PDN 15012 and Co 86032. A higher root CEC may indicate greater exchange sites on the root surface and potentially stronger nutrient acquisition capacity; however, it should be interpreted along with root length, root biomass and field nutrient uptake data (Heintze, 1961; Chapman, 1965; Marschner, 2012; Szatanik-Kloc et al., 2017).

Table 4. Root CEC at 120 days (cmol(+) kg-1).

CEC = replicate reading; values are mean ± SE (n = 3).

Variety	RI	RII	RIII	CEC mean ± SE
Co 86032	110.00	103.33	103.33	105.56 ± 2.22
CoM 0265	103.33	96.67	110.00	103.33 ± 3.85
CoVSI 03102	126.67	123.33	130.00	126.67 ± 1.92
VSI 08005	93.33	96.67	110.00	100.00 ± 5.09
MS 10001	93.33	96.67	100.00	96.67 ± 1.92
CoVSI 18121	103.33	83.33	96.67	94.44 ± 5.88
PDN 15012	126.67	106.67	113.33	115.56 ± 5.88
PDN 13007	116.67	96.67	93.33	102.22 ± 7.29

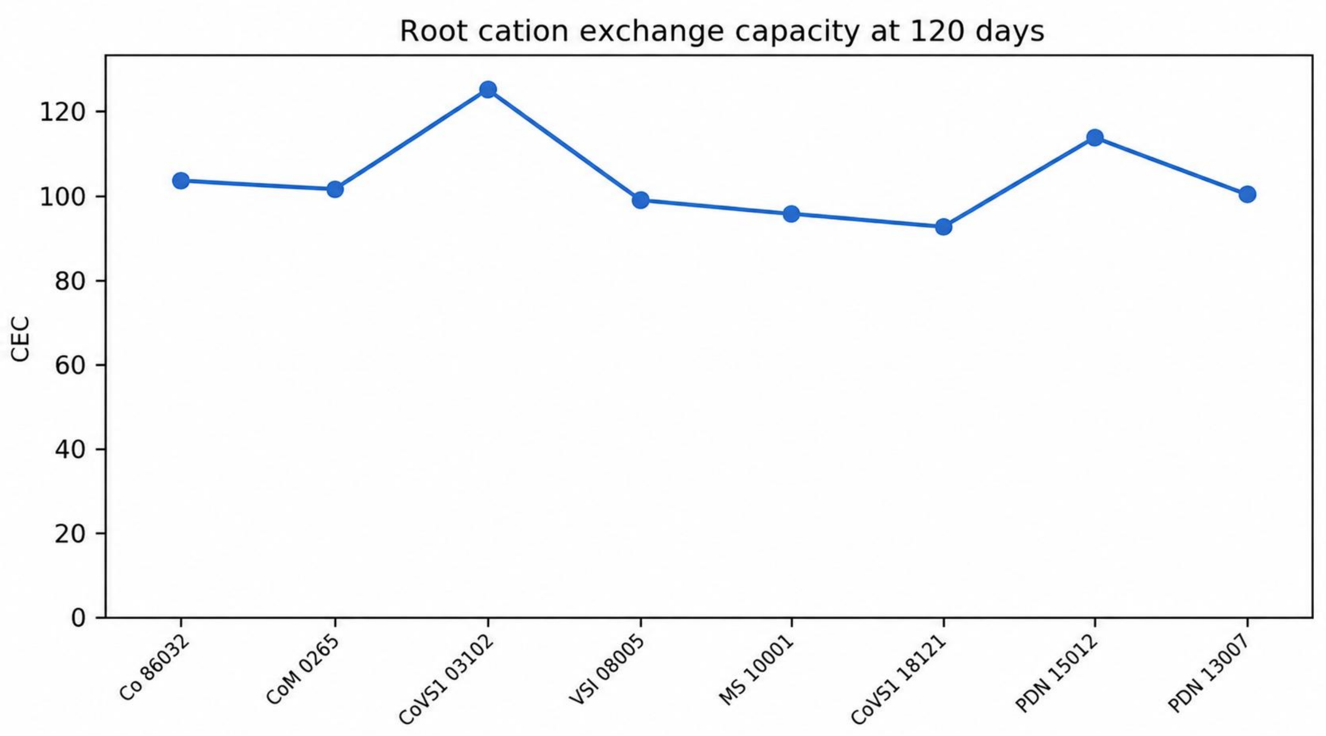

Figure 6. Root CEC of sugarcane varieties at 120 days.

5. DISCUSSION

The hydroponic system revealed appreciable genotypic variation in early root elongation, shoot elongation and root:shoot balance. CoM 0265 expressed a strong early root-length response at 60 days, whereas PDN 13007, VSI 08005 and MS 10001 showed stronger root elongation at 90 days. This change in varietal ranking indicates that early root vigour and later formative-phase root elongation are distinct but complementary screening traits.

VSI 08005 produced the highest shoot length at 90 days and also maintained one of the highest root lengths, suggesting balanced root and shoot growth under hydroponics. CoM 0265 maintained the highest root:shoot length ratio at both stages, while MS 10001 combined comparatively high root length with vigorous shoot growth. Such combinations are desirable because adequate root development can support water and nutrient acquisition while sustaining shoot growth during stress (Smith et al., 2005; Inman-Bamber and Smith, 2005; Wasaya et al., 2018).

Root growth has a practical connection with yield through its influence on soil exploration, water uptake, nutrient uptake, stalk elongation and biomass accumulation (Smith et al., 2005; Lynch, 1995). In field-grown sugarcane, deeper and more extensive roots can help maintain canopy function during drought and support stalk growth when water and nutrients are limiting (Smith et al., 2005; Inman-Bamber and Smith, 2005). In the present study, the favourable root-growth responses of CoM 0265, VSI 08005, MS 10001 and PDN 13007 support their prioritization for subsequent drought screening. Customized low-cost platforms developed at ICAR-SBI have likewise been proposed for rapid sugarcane root phenotyping and early drought-tolerance screening (Valarmathi et al., 2018; Ramanathan et al., 2021).

The CEC results indicated that CoVSI 03102 had the highest root exchange capacity at 120 days, although it was not the top variety for root length. This suggests that root-surface chemical activity and root elongation represent different components of root-system performance (Heintze, 1961; Marschner, 2012; Szatanik-Kloc et al., 2017). Therefore, future screening should combine root length, root biomass, root volume, CEC and nutrient-uptake measurements because no single root trait fully represents water and nutrient acquisition capacity (Smith et al., 2005; Inman-Bamber and Smith, 2005).

The root CEC values ranged from 94.44 to 126.67 cmol(+) kg-1 at 120 days under the present analytical conditions. Direct comparison with other reports should be made cautiously because root CEC is influenced by plant species, genotype, root age, the proportion of young absorbing roots, washing and saturation procedures, solution pH and unit expression (Heintze, 1961; Chapman, 1965; Marschner, 2012). CoVSI 03102 therefore showed the greatest root-surface exchange capacity within this experiment, but the result should be confirmed through repeated measurements together with root biomass and nutrient-uptake data.

The use of black plastic film around the jars was appropriate because excluding light from the nutrient solution reduces algal growth and helps maintain cleaner root-zone conditions (Resh, 2013). The plastic support frame maintained seedlings in an upright position and allowed uniform exposure of roots to the nutrient solution (Hoagland and Arnon, 1950; Resh, 2013). Overall, the low-cost setup appears suitable as an easy and early screening method for sugarcane root traits relevant to drought adaptation, consistent with the rapid root-phenotyping approach reported by Ramanathan et al. (2021).

6. CONCLUSION

The hydroponic system differentiated sugarcane varieties for root length, shoot length, root:shoot length ratio and root CEC during the formative phase. CoM 0265 showed rapid early root elongation and the highest root:shoot length ratio, while VSI 08005, MS 10001 and PDN 13007 showed strong root elongation by 90 days. VSI 08005 also recorded the highest shoot length, and CoVSI 03102 recorded the highest root CEC. The simple hydroponics methodology therefore appears useful for easy and early screening of sugarcane genotypes for root vigour and preliminary identification of root traits associated with drought adaptation. On the basis of the combined root and shoot responses, CoM 0265, VSI 08005, MS 10001 and PDN 13007 may be prioritized for further controlled drought-screening experiments.

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