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EFFECT OF GROWTH MEDIA ON GROWTH AND NUTRIENT UPTAKE OF COCOA SEEDLING VARIETIES NIGERIA.

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ABSTRACT

Cocoa (*Theobroma cacao* L.) is a vital economic crop that serves as a major source of income for many tropical countries and is the raw material for the global chocolate industry. However, poor seedling vigor due to suboptimal nursery growth media often limits successful establishment and productivity in the field. Hence, this study was carried out to determine the effect of different growth media on the growth and nutrient uptake of cocoa seedling varieties at the Teaching and Research Farm, Ladoke Akintola University of Technology, Ogbomoso.

Factors considered were of three growth media (topsoil only, topsoil + poultry manure, and topsoil + sawdust), and six cocoa varieties (TC1, TC2, TC3, TC4, TC5, and TC6). The 3 x 6 factorial experiment was arranged in a Completely Randomized Design (CRD) with three replicates. Data on plant height, number of leaves, leaf area, and nutrient uptake (N, P, K, Ca and Mg) were analyzed using ANOVA, and means were separated using Duncan's Multiple Range Test (DMRT) at 5% significance level.

Results revealed that both growth media and variety significantly influenced all measured growth and nutrient parameters, with significant interactions. Across all sampling periods, seedlings grown in TS+PM exhibited superior performance in height, leaf number, leaf area, and nutrient uptake compared with TS and TS+SD. At 12 WAS, seedlings in TS+PM attained the greatest mean height (19.21 cm) and leaf area (40.55 cm²). Among the varieties, TC2 produced the tallest seedlings, whereas TC5 and TC6 recorded the widest leaf area and highest nutrient accumulation (N = 0.94%, P = 4.54%, K = 0.67%, Ca = 0.56%, Mg = 0.41%). The interaction between TS+PM and varieties TC2, TC5 and TC6 resulted in the most vigorous seedlings. The study concludes that integrating poultry manure with topsoil enhances cocoa seedling growth and nutrient composition.

Keywords: *Cocoa varieties, growth media, poultry manure, nutrient uptake, nursery management*

INTRODUCTION

Cocoa (*Theobroma cacao* L.), a tree belonging to the family Malvaceae (Alverson, 2009), is among the most economically important tropical perennial crops. Its seeds serve as the essential raw material for the production of chocolate, cocoa powder, beverages, confectioneries and numerous pharmaceutical products. Moreover, cocoa cultivation supports the livelihoods of millions of small-holder farmers in humid tropical regions. West Africa alone accounts for approximately 70 % of global cocoa output, with Côte d'Ivoire, Ghana, Nigeria and Cameroon as leading producers (FAOSTAT, 2014). Nigeria, in particular, ranks as the fourth-largest producer, with an estimated annual yield of about 485,000 metric tons (FAOSTAT, 2014). Beyond its export value, cocoa also has local uses in traditional medicine to treat gastrointestinal ailments (Opeke, 2005). Cocoa exhibits significant genetic diversity, with varieties broadly categorized into Criollo, Forastero, and Trinitario groups. The Forastero type particularly the Amazon and Amelonado varieties predominates in West Africa due to its high yield potential, disease tolerance, and adaptability to tropical climates (Toxopeus, 1985; Adenuga *et al*., 2013). In Nigeria, improved hybrid varieties developed by the Cocoa Research Institute of Nigeria (CRIN) have been widely adopted. These hybrids combine the high yield and vigor of Amazon types with the quality traits of Amelonado, resulting in improved productivity and resilience under varied soil and climatic conditions (CRIN, 2018).

Nutritionally, cocoa beans are rich in

carbohydrates, fats, proteins, essential minerals and bioactive phytochemicals which have been associated with antioxidant, anti-inflammatory and cardioprotective effects (Afoakwa *et al*., 2008). Despite this significance, cocoa production in Nigeria has declined since the early 1970s due to factors including ageing plantations, sub-optimal agronomic practices, pest and disease burdens and, importantly, soil nutrient depletion (IFDC, 2009). Indeed, inadequate soil fertility management and very low inorganic fertilizer use reported to average around 8 kg ha^{-1} in many African cocoa systems have contributed to diminishing yields (Ogunlade and Aikpokpodion, 2009; CRIN Annual Report, 2016-2018).

Within cocoa establishment systems, the nursery phase is critical for ensuring strong seedling vigor and successful field transplantation. The growth media is a substrate in which seedlings are raised, and are fundamental to seedling health, influencing germination, root development, nutrient uptake and early shoot growth. Optimal media must offer sufficient aeration, drainage and nutrient supply. Organic amendments such as poultry manure, compost or sawdust have been shown to improve substrate physical structure, water retention and microbial activity, thereby supporting seedling performance (Ayanlaja, 2002; Moyin-Jesu, 2008). While such organic-based media have been successfully applied to other perennial crops (ecoffee, tea) with improved growth and nutrient status (Michori, 1998; Ipinmoroti and Adeoye, 2002), their application in cocoa nursery systems has been less extensively explored.

In many cocoa nurseries in Nigeria, the use of poor-quality topsoil or unamended substrates results in seedlings with limited root and shoot development, poor nutrient uptake and low transplantation survival (Famuwagun and Agele, 2011; Ibiremo, 2012). Given the centrality of seedling quality in achieving sustainable cocoa production, there is a strong justification for examining how different growth media affect the early growth and nutrient uptake of cocoa seedlings across varietal genotypes. Therefore, this study was conducted to evaluate the effect of three growth on the growth performance and nutrient uptake of cocoa seedling varieties under nursery conditions.

Materials and Methods

Experimental Study Area: The experiment was conducted at the Teaching and Research Farm, Ladoke Akintola University of Technology (LAUTECH). Ogbomoso lies between latitude 8°10′ N and longitude 4°10′ E with highest rainfall (212.30mm) in August and (141.10 mm) in October. The environment recorded its average relative humidity of 72%, average maximum temperature 34.6°C and average minimum temperature 21.5°C (NIMET, 2023).

Source of Growth Medium Materials: Cured poultry manure was collected from Teaching and Research Farm, Ladoke Akintola University of Technology, Ogbomoso, Oyo State. Dry Sawdust was collected from Ogbomoso Central Saw-mill Factory, New Waso Market, Ogbomoso, Oyo State.

Source of Coca Seeds: Cocoa seed varieties (TC1-TC6) were sourced from Cocoa Research Institute of Nigeria (CRIN), Ibadan, Oyo State. Cocoa TC1–TC6 hybrids are early-bearing, pest-tolerant varieties producing high-quality beans with yields of 1.5–2.3 t/ha across diverse Nigerian cocoa ecologies (CRIN, 2021).

Pot fillings and establishment: Topsoil (0–15 cm depth) was collected from the LAUTECH Teaching and Research Farm, Ogbomoso, Oyo State, using a spade. The soil was air-dried, sieved through a 2 mm mesh, and thoroughly mixed to ensure homogeneity. Composite soil samples were taken for laboratory analysis of physical and chemical properties. Polythene pots (20 × 25 cm) were perforated at the base to enhance drainage and aeration, then filled with 10 kg of the respective growth media. For mixtures involving soil and sawdust were combined at a 3:1 ratio (by weight). A total of 104 pots were prepared for the experiment. Cured poultry manure collected was also analyzed for nutrient composition.

	Nutrient contents (%)		
Fertilizers	N	P	K
Poultry manure	2.90	1.32	1.69

Treatment and Experimental Design:
Factors considered were six cocoa varieties namely; TC1, TC2, TC3, TC4, TC5 and TC6, and three growth media (topsoil only, topsoil + poultry manure, and topsoil + sawdust), arranged in a 3 × 6 factorial layout. Treatments were assigned using a Completely Randomized Design (CRD) with three replications.

Agronomic Practices
Cocoa seeds were sown directly into poly-pots at a depth of 2 cm, two seeds per pot. Pots were arranged in a nursery under cashew shade to simulate natural conditions, with 0.5 m spacing within replicates and 1.0 m between replicates. Watering was applied at establishment and every three days thereafter using watering can. Thinning to one seedling per pot was performed at 2 weeks after sowing (WAS). Rouging was carried out as emergence of weeds, and pests were controlled with cypermethrin (40 ml/20 L)

applied at 4 WAS. Z-force was applied at planting.

Data Collection and Analysis

Data collection commenced at 4 WAS and continued at four-week interval for 12 weeks. Data collected include plant height using meter rule, number of fully expanded leaves were manually counted, leaf area using Pandey and Singh (2011) method: length × width × correction factor, where correction factor = 0.75

Nutrient Uptake: Three healthy leaves were collected with the use of a clean and sharp knife from each plant within every pot, thereby ensuring a representative sample. The leaves were bulked by packing them into envelopes and subsequently oven-dried at 65°C until a constant weight was reached. Potassium, calcium, and magnesium content of the plant samples were determined with an automatic Atomic Absorption Spectrophotometer (Unicam Model 929, Unicam Cambridge, England). The total N and P concentrations of the leaves were determined using Kjeldahl and photometric method, respectively. Data collected were subjected to Analysis of Variance (ANOVA) and means were separated using Duncan's Multiple Range Test (DMRT) at 5% significance level.

Results and Discussion

Physical and chemical properties of the experimental soil

The physical and chemical properties of the experimental soil are presented in Table 2. The soil was classified as sandy loam, consisting of 82.95% sand, 12.3% silt, and 4.75% clay. The soil pH (6.27) was slightly acidic. The total nitrogen (0.37%) was moderate, while the available phosphorus (6.38 mg/kg) was low. The organic carbon (2.57%) was moderately high. Among the exchangeable cations, Ca^{2+} (2.11 cmol/kg) predominated, followed by Mg^{2+} (0.74 cmol/kg), K^{+} (0.34 cmol/kg), and Na^{+} (0.25 cmol/kg). These findings agree with earlier reports by Agbenin (1995) and Akinrinde and Obigbesan (2000) that tropical soils are often sandy, weak in nutrient retention, and low in phosphorus due to fixation by Fe and Al oxides. The slightly acidic reaction observed supports assertion that pH 6.0–6.5 enhances macronutrient availability, while the moderate nitrogen and organic carbon levels align with Udo et al. (2009), who associated such soils with fair fertility and good structural stability.

Effect of growth media and variety on the plant height (cm) of cocoa seedlings

The effect of growth media and cocoa varieties on the plant height of cocoa seedlings at different sampling periods is presented in Table 3. Results showed that plant height of cocoa seedlings was significantly influenced by growth media and variety at all sampling stages. Seedlings grown in topsoil + poultry manure (TS+PM) were tallest (11.02, 13.81, 19.21 cm at 4, 8, 12 WAS), followed by topsoil alone, while topsoil + sawdust (TS+SD) produced the shortest seedlings. Among varieties, TC2 and TC4 consistently exhibited superior height, whereas TC3 recorded the least growth. The enhanced growth in TS+PM reflects improved nutrient availability, while varietal differences suggest inherent genetic vigor. These results align with previous studies showing poultry manure improves cocoa seedling growth (Adjaloo *et al*., 2017; Osei-Bonsu *et al*., 2019), and that cocoa hybrids differ in early growth performance (Anim-Kwapong and Asante, 2017).

The interaction between growth media and variety was significant. At all stages, TC2 and TC4 performed best in TS+PM or topsoil, while TC3 in TS+SD had the lowest height. This indicates that the growth response of each variety depends on the nutrient status of the medium. Reduced growth in TS+SD may result from nitrogen immobilization during decomposition (Awodun *et al*., 2007, Oladokun and Ojeniyi, 2014).

Effect of growth media and variety on number of leaves of cocoa seedlings

Growth media and variety significantly affected the number of leaves of cocoa seedlings (Table 4). At 4 WAS, seedlings in topsoil + poultry manure (TS+PM) had the highest leaf number (3.37), followed by TS+SD (3.04), while topsoil had the least (2.65). Leaf number increased with age, and at 8 and 12 WAS, seedlings in TS+PM and TS+SD maintained high leaf counts. Varieties TC2 and TC6 consistently produced more leaves, indicating better vigor and nutrient use efficiency. The enhanced leaf production in TS+PM may be as a result of improved nutrient availability and soil fertility, while sawdust improved aeration for better leaf expansion. These findings agree with Ayeni *et al*. (2008) and Awodun *et al*. (2007), who reported that poultry manure and sawdust enhance vegetative growth through improved soil fertility and structure. The varietal variation observed aligns with Anim-Kwapong and Asante (2017) and Osei-Bonsu *et* *al*. (2019), who noted genotypic differences in cocoa leaf development.

The interaction between growth media and variety was significant at 12 WAS. TC6 in TS+SD and TC1–TC2 in TS+PM recorded the highest leaf numbers, while TC3 in topsoil had the lowest. This indicates varietal differences in response to media types, with vigorous hybrids performing best under nutrient-rich and aerated conditions. The media and variety interaction supports Aiyelari *et al.* (2017), emphasizing the synergistic effect of genotype and organic amendment on cocoa seedling growth.

Effect of growth media and variety on leaf area (cm^2) of cocoa seedlings

The effect of growth media and cocoa varieties on leaf area of cocoa seedlings at different sampling periods is presented in Table 5. Results showed that leaf area of cocoa seedlings was significantly influenced by both growth media and variety throughout the sampling period. At 4 weeks after sowing (WAS), differences among treatments were not significant, indicating similar early leaf development across media and varieties. However, at 8 and 12 WAS, seedlings grown in topsoil + sawdust (TS+SD) recorded the highest mean leaf area (28.07 and 43.14 cm^2), followed closely by topsoil (25.53 and 43.62 cm^2), while topsoil + poultry manure (TS+PM) produced smaller leaf areas (24.26 and 40.55 cm^2). The superior leaf expansion in TS+SD and topsoil could be attributed to improved soil structure, aeration, and moderate nutrient release that favor photosynthetic activity. Among the varieties, TC5 and TC6 consistently produced significantly higher leaf areas at 8 and 12 WAS, reflecting inherent genetic vigor, efficient nutrient use, and greater adaptability. These findings corroborate Adjaloo et al. (2017) and Osei-Bonsu et al. (2019), who reported that well-aerated, organic-based media enhance cocoa seedling leaf development, and are in line with Anim-Kwapong and Asante (2017), who attributed varietal differences in leaf area to genetic variability among cocoa hybrids.

A significant interaction was observed between growth media and variety at later growth stages. At 8 and 12 WAS, TC5 and TC6 grown in TS+SD or topsoil had the largest leaf areas, whereas TC1–TC3 in TS+PM had the smallest. This pattern indicates that the growth response of each variety is strongly influenced by the nutrient and physical characteristics of the media. The enhanced leaf area in sawdust-amended media can be attributed to improved moisture conservation and aeration, which favor leaf expansion and canopy formation, while the lower leaf area in TS+PM may result from temporary nutrient immobilization during organic matter decomposition. Similar observations were reported by Awodun *et al*. (2007), who found that sawdust improves soil physical conditions, and by Ayeni *et al*. (2008), who noted that nutrient mineralization from poultry manure may be delayed at early stages, temporarily limiting growth.

Effect of growth media and variety on nutrient uptake (%) of cocoa seedlings

Growth media and variety significantly affected nutrient uptake of cocoa seedlings (Table 6). Seedlings grown in topsoil + poultry manure (TS+PM) recorded the highest uptake of N, P, K, Ca, and Mg, followed by topsoil + sawdust (TS+SD), while topsoil alone had the least values. Among varieties, TC5 and TC6 consistently exhibited higher nutrient uptake, indicating superior genetic potential for nutrient absorption. The improved uptake in TS+PM reflects enhanced nutrient availability through organic matter mineralization, while the moderate performance of TS+SD suggests benefits from improved aeration and moisture retention. These findings agree with Ayeni *et al*. (2008) and Aiyelari *et al*. (2017), who reported improved nutrient uptake with poultry manure application. The superior performance of TC5 and TC6 aligns with Anim-Kwapong and Asante (2017) and Osei-Bonsu *et al*. (2019), who observed varietal variation in cocoa nutrient use efficiency.

The interaction between growth media and variety was also significant across all nutrients. TC6 in TS+PM recorded the highest N (1.08%), P (4.90 mg/kg), K (0.78%), Ca (0.60 cmol/kg), and Mg (0.49 cmol/kg), followed by TC5 in TS+PM. In contrast, TC1–TC3 in topsoil had the lowest uptake. This indicates that nutrient enrichment through poultry manure is more effective in vigorous genotypes with higher nutrient use efficiency. The positive media–variety interaction supports Adjaloo *et al*. (2017) and Babalola *et al*. (2015), who found that organic amendments enhanced nutrient uptake more effectively in improved cocoa hybrids.

Table 2: Chemical and physical properties of the top soil used for the experimental site

Soil characteristics	Values
Physical characteristics	
Sand (%)	82.95
Silt (%)	12.30 4.75
Clay (%) Textural Class	Sandy loam
Chemical characteristics PH	
(H_2O)	
Total N (%)	6.27
Available P (mg/kg) Organic	0.37
carbon	6.38
	2.57
Exchangeable cations (C mol/kg)	
Ca^{2+}	
Mg^{2+}	2.11
K^{+}	0.74
Na^{+}	0.34
	0.25

Table 3: Effect of growth media and variety on the plant height of cocoa seedling

	Plant Height (cm)			
Variety	Topsoil	TS+PM	TS+SD	MeanVar
		4WAS		
TC1 TC2	9.23 e	10.05 cd	8.29 f	9.19
TC3 TC4	11.46 b	12.48 a	10.29 c	11.41
TC5 TC6	8.40 f	9.15 e	7.55 f	8.37
MeanGM	10.11 cd	11.01 b	9.08 e	10.07
	10.73 c	11.69 ab	9.64 d	10.69
T C 1	10.78 c	11.74 a	9.69 d	10.74
T C 2	10.12	11.02	9.09	
T C 3			8 WAS	
	10.18 e	8.89 f	8.51 f	9.19
	18.93 a	16.53 a	15.82 b	17.09
	15.26 b	13.32 c	12.76 cd	13.78
		14.97 b	14.33 bc	
TC5 TC6	17.46 a	15.24 b	14.59 b	15.76
MeanGM	15.94 b	13.91 c	13.32 c	14.39
	15.82	13.81	13.22	
TC1 TC2			12WAS	
TC3 TC4	23.54 b	20.20 d	19.95 d	21.23
TC5 TC6	22.23 cd	19.08 d	18.84 d	20.05
MeanGM	18.02 e	15.47 e	15.27 e	16.25
	26.53 a	22.77 c	22.49 c	23.93
	21.41 d	18.38 d	18.15 d	19.31
	22.55 c	19.36 d	19.12 d	20.34
	22.38	19.21	18.97	

TS+PM= Topsoil + poultry manure, TS+SD= Topsoil+sawdust, MeanGM= growth media mean, MeanVar= variety mean, Mean with the same letters within the column are not significantly different by DMRT at P=0.05

Table 4: Effect of growth media and variety on the number of leaves of cocoa seedling

	Number of leaves			
Variety	Topsoil	TS+PM	TS+SD	MeanVar
		4WAS		
TC1 TC2	2.48 d	3.20 b	2.87 c	2.85
TC3 TC4	2.48 d	3.20 b	2.87 c	2.85
TC5 TC6	2.59 c	3.31 b	2.98 b	2.96
MeanGM	3.37 b	4.09 a	3.76 a	3.74
	2.48 d	3.20 b	2.87 c	2.85
	2.48 d	3.20 b	2.87 c	2.85
	2.65	3.37	3.04	
		8 WAS		
TC1	8.64 b	8.70 b	7.64 c	8.33
TC2	9.64 a	9.70 a	8.64 b	9.33
TC3	9.20 a	9.26 a	8.20 b	8.89
TC4	8.09 b	8.15 b	7.09 d	7.78
TC5	7.87 c	7.93 c	6.87 d	7.56
TC6	8.87 b	8.93 a	7.87 c	8.56
MeanGM	8.72	8.78	7.72	
		12WAS		
TC1 TC2	22.76 a	23.03 a	24.53 a	23.44
TC3 TC4	22.32 a	22.59 a	24.09 a	23.00
TC5 TC6	15.88 c	16.15 c	17.65 b	16.56
MeanGM	17.99 b	18.26 b	19.76 b	18.67
	17.43 b	17.70 b	19.20 b	18.11
	23.99 a	24.26 a	25.76 a	24.67
	20.06	20.33	21.83	

TS+PM= Topsoil + poultry manure, TS+SD= Topsoil+sawdust, MeanGM= growth media mean, MeanVar= variety mean, Mean with the same letters within the column are not significantly different by DMRT at P=0.05

Table 5: Effect of growth media and variety on the leaf area of cocoa seedling

	Leaf area			
Variety	Topsoil	TS+PM	TS+SD	MeanVar
		4WAS		
TC1 TC2	13.81 a	12.57 a	13.26 a	13.21
TC3 TC4	12.28 a	11.04 a	11.73 a	11.68
TC5 TC6	12.82 a	11.58 a	12.27 a	12.22
MeanGM	13.40 a	12.16 a	12.85 a	12.80
	13.38 a	12.14 a	12.83 a	12.78
	13.17 a	11.93 a	12.62 a	12.57
	13.14	11.90	12.59	
		8 WAS		
TC1	24.58 b	23.31 b	27.12 b	25.00
TC2	25.22 b	23.95 b	27.76 b	25.64
TC3	23.95 b	22.68 b	26.48 b	24.37
TC4	23.86 b	22.59 b	26.40 b	24.28
TC5	29.34 a	28.08 a	31.88 a	29.77
TC6	26.24 b	24.98 b	28.78 ab	26.67
MeanGM	25.53	24.26	28.07	
		12WAS		
TC1 TC2	40.07 b	37.32 b	39.92 b	39.10
TC3 TC4	41.58 b	38.84 b	41.43 b	40.62
TC5 TC6	41.64 b	38.90 b	41.50 b	40.68
MeanGM	43.36 b	40.62 b	43.22 b	42.40
	46.82 a	44.07 a	46.67 a	45.85
	46.27 a	43.52 a	46.12 a	45.30
	43.62	40.55	43.14	

TS+PM= Topsoil + poultry manure, TS+SD= Topsoil+sawdust, MeanGM= growth media mean, MeanVar= variety mean, Mean with the same letters within the column are not significantly different by DMRT at P=0.05

Table 6: Effect of growth media and variety on the nutrient uptake of cocoa seedling

	Nutrient Uptake (%)			
Variety	Topsoil	TS+PM	TS+SD	MeanVar
		N		
TC1	0.70f	0.85d	0.74e	0.76
TC2	0.75e	0.89cd	0.73e	0.79
TC3	0.80d	0.92c	0.81d	0.84
TC4	0.76e	0.88cd	0.77de	0.80
TC5	0.92b	1.02b	1.00b	0.98
TC6	0.90b	1.08a	1.02a	1.00
MeanGM	0.81	0.94	0.84	
		P		
TC1	3.60f	3.90e	3.78e	3.76
TC2	3.78e	4.00d	3.95d	3.91
TC3	3.90d	4.20c	4.22c	4.11
TC4	3.95d	4.30bc	4.02cd	4.09
TC5	4.20c	4.50b	4.30b	4.34
TC6	4.50b	4.90a	4.85a	4.75
MeanGM	3.81	4.54	4.14	
		K		
TC1	0.46e	0.58d	0.49e	0.51
TC2	0.52d	0.61cd	0.55d	0.56
TC3	0.55d	0.63c	0.57c	0.58
TC4	0.54d	0.62c	0.56c	0.56
TC5	0.64c	0.74b	0.66b	0.68
TC6	0.62c	0.78a	0.58c	0.66
MeanGM	0.53	0.67	0.59	
		Ca		
TC1	0.32e	0.42d	0.35e	0.36
TC2	0.40c	0.49b	0.48b	0.46
TC3	0.42c	0.51b	0.50b	0.48
TC4	0.40c	0.47c	0.49b	0.46
TC5	0.33d	0.56a	0.36d	0.42
TC6	0.50b	0.60a	0.58a	0.59
MeanGM	0.35	0.56	0.47	
		Mg		
TC1	0.23f	0.33e	0.25f	0.27
TC2	0.33d	0.39cd	0.33d	0.35
TC3	0.35c	0.42bc	0.35c	0.37
TC4	0.25f	0.35d	0.27e	0.29
TC5	0.33d	0.37d	0.33d	0.34
TC6	0.39b	0.49a	0.46a	0.45
MeanGM	0.27	0.41	0.35	

Topsoil+PM= Topsoil + poultry manure, Topsoil+SD= Topsoil+sawdust, Mean with the same letters within the column are not significantly different by DMRT at P=0.05

Conclusion

The study demonstrated that both growth media and varietal differences significantly influenced positively the growth performance and nutrient uptake of cocoa seedlings. Varieties TC5 and TC6 consistently exhibited superior plant height, leaf area, and nutrient absorption, Among the media, topsoil amended with poultry manure (topsoil + PM) enhanced early seedling growth and nutrient uptake due to its rich organic matter and balanced nutrient release, while topsoil alone and topsoil + sawdust supported comparable performance at later stages.

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