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Efficiency of the multiple shoot removal technique for enhancing seed multiplication in selected commercial cassava (*Manihot esculenta* Crantz) varieties in Tanzania

Eficiencia de la técnica de eliminación de brotes múltiples para mejorar la multiplicación de semillas en variedades comerciales seleccionadas de yuca (*Manihot esculenta* Crantz) en Tanzania

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Abstract

Cassava (*Manihot esculenta* Crantz) is a major staple crop across Africa, Asia, and South America, where it supports the livelihoods of millions of people. However, the availability of improved planting material is constrained due to low seed propagation rates, compelling farmers to rely on local cultivars that often exhibit low yield potential and high susceptibility to diseases. Developing reliable seed multiplication techniques is therefore essential to increase the availability of improved varieties and boost cassava production. This study evaluated the effectiveness of the Multiple Shoot Removal Technique (MSRT) for the multiplication of improved cassava varieties in Tanzania. Six varieties were assessed using a completely randomized design. Growth parameters, including shoot formation, root induction, acclimatization, and field establishment, were recorded and analyzed using R statistical software. MSRT significantly increased the cassava multiplication ratio by up to five-fold compared to conventional methods. The TARRICASS4 variety showed a substantially higher multiplication rate (1:80) than the other varieties. Plantlet production efficiency was positively influenced by the shoot number and regeneration rate following ratooning, root number, and length during induction, and the survival rate of shootlets across the multiplication stages. These findings support the use of MSRT as a viable approach to enhance the availability of high-quality cassava planting materials and improve cassava production. Further research is recommended to optimize the application of plant growth regulators for improving shoot regeneration and ratoon growth performance.

Keywords: Cassava shootlet, high-quality planting material, micro-propagation, root induction.

Resumen

La yuca (*Manihot esculenta* Crantz) es un cultivo alimentario de gran importancia en África, Asia y Sudamérica, que representa el sustento de millones de personas. Sin embargo, la disponibilidad de material de siembra mejorado se ve afectada por una baja tasa de propagación de semillas, lo que obliga a los agricultores a depender de variedades locales con bajo potencial de rendimiento y alta susceptibilidad a enfermedades. Es crucial desarrollar tecnologías confiables de multiplicación de semillas para aumentar la disponibilidad de variedades mejoradas e impulsar la producción de yuca. Este estudio evaluó la eficacia de la técnica de remoción de brotes múltiples (MSRT) en la multiplicación de variedades mejoradas de yuca en Tanzania. Se evaluaron seis variedades en un experimento con diseño completamente aleatorizado. Se recopilaron datos sobre los parámetros de crecimiento de la formación de brotes, la inducción de raíces, la aclimatación y el establecimiento en campo, y se analizaron posteriormente con el programa estadístico R. La MSRT quintuplicó la tasa de multiplicación de la yuca en comparación con los métodos convencionales. La variedad TARRICASS4 presentó una tasa de multiplicación sustancialmente mayor (1:80) que las otras variedades. La eficiencia productiva de las plántulas se vio influenciada positivamente por el número y la tasa de regeneración de brotes tras la soca, el número y la longitud de las raíces formadas durante la inducción, y la tasa de supervivencia de los brotes a lo largo de las etapas de multiplicación. Estos hallazgos respaldan el uso de la MSRT como un método viable para mejorar la disponibilidad de materiales de siembra de alta calidad y aumentar la producción de yuca. Se recomienda realizar nuevas investigaciones para aumentar el impacto de los reguladores de crecimiento vegetal en la mejora de la regeneración y la tasa de crecimiento de los brotes tras la soca.

Palabras clave: brote de yuca, inducción de raíces, material de siembra de alta calidad, micropropagación.

Introduction

Cassava (*Manihot esculenta* Crantz) is one of the primary staple crops across the tropical regions of Africa, Asia, and Latin America, where it supports the livelihoods of over 800 million people (Wang *et al.*, 2018). It is rich in carbohydrates and serves as a major daily source of nutrition for approximately 40 % of the Sub-Saharan African population (Garcia-Oliveira *et al.*, 2020). Cassava's ability to thrive in low-fertility soils and under limited rainfall, combined with the long storage life of its roots, contributes to its widespread cultivation worldwide (Alves, 2002). In Tanzania, cassava is primarily cultivated by smallholder farmers, either as a sole crop or intercropped with other annual or perennial species (Hillocks *et al.*, 2002; Kidasi *et al.*, 2021). In Africa, most cassava production is used for human consumption, while some is utilized for livestock feed and industrial purposes such as the production of starch, bread, biscuits, and ethanol (Falade and Akingbala, 2010).

Cassava production in Africa is estimated at approximately 200 million metric tons, representing more than 58 % of the global production (Otekunrin and Sawicka, 2019). In Tanzania, average cassava yields range between 8 t ha^{-1} and 12 t ha^{-1} of fresh roots, which is significantly lower than the average yield of 23 t ha^{-1} reported in Thailand (Kongsil *et al.*, 2024; Ministry of Agriculture, 2020). The widespread use of pathogen- and pest-infected local cultivars often reduces cassava productivity (Oka *et al.*, 1987). Douthwaite (2020) and Kidasi *et al.* (2021) reported that approximately 99 % of Tanzanian farmers still rely on local varieties characterized by low yield potential and high susceptibility to major pests and diseases.

Cassava is primarily propagated through lignified stem cuttings aged 9 to 12 months (Oka *et al.*, 1987). Botanical seeds are used exclusively for breeding purposes due to their genetic heterogeneity, high dormancy, and poor root development on the mother plant. Moreover, cassava seedlings typically develop only a single, thick taproot, making them economically unfeasible for farmers (Alves, 2002; Hillocks *et al.*, 2002). Additionally, poor seed setting and variation among botanical seeds limit their production potential (Hillocks *et al.*, 2002). Using quality planting material (QPM) promotes higher sprouting rates and results in healthier, more vigorous plants capable of producing a greater number of commercial roots (Sheat *et al.*, 2024). However, access to QPM in Tanzania remains limited due to the crop's low multiplication rate, long vegetative cycle, poor storability, and high distribution costs resulting from the bulkiness of planting materials (Escobar *et al.*, 2006). Enhancing the availability and accessibility of QPM requires the development and adoption of innovative technologies for large-scale propagation.

Micropropagation techniques, such as tissue culture (TC) and semi-autotrophic hydroponics (SAH), have proven effective in producing millions of disease-free cassava planting materials (Ospina *et al.*, 2007; Kidasi *et al.*, 2021). Tissue culture employs nodal explants—including leaves, apical meristem, buds, and roots—to rapidly generate genetically identical plantlets (Abd El-Alla, 2013). However, the high investment costs and elevated mortality rates of plantlets (up to 95 %) during the acclimatization stage have limited the adoption of these technologies, particularly in developing countries (Ospina *et al.*, 2007; Shiji *et al.*, 2014).

Studies by Ospina *et al.* (2007) and Feyisa (2021) have demonstrated that success of the TC approach largely depends on the response of cassava genotypes to treatments during root induction, elongation, shoot initiation, and plant development. In this context, Multiple Shoot Removal Technique (MSRT) has emerged as a robust and practical alternative, especially in regions where conventional systems may not be feasible. Therefore, this study aims to evaluate the effectiveness of MSRT for multiplying selected Tanzanian commercial cassava varieties using locally available and cost-effective materials.

Material and methods

Description of the study area

The screenhouse experiment was conducted at TARI Naliendele, located at 10°22' S, 40°10' E, and 120 m above sea level (Imakumbili *et al.,* 2019. Growth chambers were constructed inside the screenhouse using softwood timber and a 0.2 mm white polythene sheet to facilitate shootlet sprouting and rooting (Figure 1). The screenhouse, measuring 8 m in height, 25 m in length, and 10 m in width, had a single door and was built with iron steel frames covered by a 0.2 mm black shade net to allow proper ventilation, prevent insect intrusion, and reduce the effects of UV radiation. The rooting and sprouting chambers measured 4 m x 10 m x 4 m and 4 m x 5 m x 4 m (height x length x width), respectively.

Experimental materials

Healthy, well-lignified stems from six cassava varieties (Kiroba, Mkuranga1, Chereko, Kizimbani, TARICASS4, and Pwani) were obtained from the cassava pre-basic seed unit established at Mtopwa, located at 10°41' S, 39°23' E in Newala District. Stems were cut into 25 cm cuttings, disinfected with 70 % ethanol, and soaked for 10 minutes in a 5 g L^{-1} fungicide solution containing Mancozeb and Cymoxanil. The cuttings were then air-dried under ambient conditions for 20 minutes. A thermometer and hygrometer were installed in each chamber to record daily temperature and relative humidity. A

Figure 1. Construction of the sprouting and rooting chambers at TARI Naliendele, Tanzania.

substrate composed of forest soil and decomposed yard manure in a 2:1 ratio was spread in the chamber to promote sprouting and healthy plant growth. Tap water was used for shootlet root initiation and for irrigation throughout the experiment.

Experimental design and procedures

Cassava cuttings from six varieties were arranged in a completely randomized design (CRD) with three replications. Twelve stem cuttings per treatment were planted horizontally, leaning along rows spaced 10 cm apart in the sprouting chamber, and then half-covered with fine soil to facilitate sprouting (Figure 2b). After three weeks, all shoots that had reached a height of 15 cm were cut, leaving at least two basal nodes to allow regeneration and the emergence of new shoots. Ratooning was performed at two-week intervals following the initial cut.

Ratooned shootlets were pruned to retain 2–3 upper leaves, soaked in a 5 g L^{-1} fungicide solution, and air-dried under cool conditions for 10 minutes. After drying, the shootlets were placed vertically into plastic vessels containing pure water to induce root formation in the rooting chamber. After 12 days of root initiation, rooted shootlets were transplanted into polythene bags filled with a soil, manure, and sand mixture at a 3:2:1 ratio for growth and acclimatization. Two weeks later, the plantlets were transferred to the field for establishment (Figure 3).

Temperature and humidity in the chamber were maintained below 35 °C and above 60 %, respectively, by misting with water, opening side sheets, and watering to prevent excessive dehydration and shootlet injury. A fungicide (5 g L^{-1}) and an insecticide (5 ml L^{-1}) were applied at two-week intervals to prevent fungal infections and control insect infestations. An NPK foliar fertilizer (Al-Nebras 40-0-0) was applied at a rate of 5 ml L^{-1} after each ratooning to promote shoot regeneration and growth. All other management practices followed the nursery management procedures described by Tarawali *et al.* (2013).

Data collection

Data collection was carried out during the stages of shoot formation, root induction, acclimatization, and field establishment. Prior to planting, data on the number of nodes, cutting diameter, moisture content, and fresh and dry weight of cuttings were recorded. The sprouting percentage and the number of shoots produced per cutting were measured three weeks after planting (WAP). The number of ratoons, rooting percentage, number and length of roots, and the survival rate of shootlets were assessed two weeks after root induction. Plantlet survival was evaluated after two weeks of acclimatization and three weeks of field establishment. Plant height and vigor were recorded for twelve plants at 3 months after planting (MAP) in the field. Additionally, five shootlets were randomly selected from each plot to determine the number and length of developed roots.

The potential of MSRT was evaluated by calculating the total number of cassava plantlets produced throughout the experiment, following the formula described by Sukmadjaja and Widhiastuti (2011), with some modifications. In this study, the n-exponential term was omitted since no sub-planting of the generated plantlets was performed. The modified formula used to determine the total number of cassava plantlets produced was as follows:

$$y = A^n \times B \times F1 \times F2 \times F3 \quad \text{(i) Original formula}$$

$$y = A \times B \times F1 \times F2 \times F3 \quad \text{(ii) Modified formula}$$

Figure 2. Preparation of cassava planting material (a) and establishment of stem cuttings in the sprouting chamber (b) at TARI Naliendele, Tanzania.

Figure 3. Sequential steps in cassava planting material multiplication using the Multiple Shoot Removal Technique (MSRT).

Where:

y = total number of shootlets/plantlets produced

n = number of sub-cuts at a given period

A = number of shootlets produced per ratooning cycle

B = number of shootlets replanted

F1 = percentage of successfully rooted shootlets during root induction

F2 = percentage of successfully acclimatized shootlets

F3 = percentage of successfully established shootlets in the field

Data analysis

Collected data were analyzed using R software version 4.3.2 (Hlavac, 2022) to determine significant differences among treatment means. The least significant difference (LSD) test was used for mean separation at a 95 % confidence interval, and correlation analysis was performed to evaluate the influence of independent variables on plantlet production efficiency.

Results and discussion

Characteristics of the planting material used

The number of nodes, stem diameter, and moisture content of cassava cuttings showed significant differences among varieties at the 5 % probability level. However, no significant differences were observed in the fresh and dry weights of the cuttings (Table 1).

The number of nodes per cutting ranged from 5 to 37, with an average of 16 nodes. The variety Chereko exhibited the highest number of nodes, which was significantly greater than those of other varieties ($p \leq 0.001$). The observed variation in node number among varieties could be attributed to differences in genetic composition (Oka *et al.*, 1987). This finding aligns with the results reported by Kalu and Agara (2020), who observed a significant variation in the number of nodes among cuttings obtained from different cassava varieties. Similarly, Oladejo and Sikiru (2019) reported that stem cuttings from the TMS 8303 cassava genotype possessed a higher number of nodes than other tested varieties.

Table 1. Mean values of stem cutting characteristics evaluated in six cassava varieties

Variety	Nodes per cutting	Stem diameter (mm)	Fresh weight (g)	Dry weight (g)	Moisture content (%)
Kiroba	18.1 b	16.87 bc	63.67	25.20 b	59.87 a
Kizimbani	14.63 cd	16.30 c	63.67	25.60 b	59.53 ab
Pwani	10.97 e	16.30 c	63.40	26.23 ab	58.63 abc
Chereko	22.43 a	17.07 bc	63.57	27.67 ab	56.50 bc
Mkuranga1	17.40 bc	17.20 ab	65.23	28.85 a	56.00 c
TARICASS4	13.13 de	18.07 a	65.10	28.67 a	55.73 c
Grand mean	16.11	16.97	64.11	27.04	57.71
LSD	3.099	1.005	6.154	2.982	3.417
CV (%)	10.574	3.255	5.293	6.062	3.255
p value	0.00012	0.0243	0.9227	0.1157	0.0707

Note. Values followed by the same letters within a column are not significantly different at the 5 % probability level ($p < 0.05$).

Stem cutting diameter ranged from 15.6 mm to 18.8 mm, with TARICASS4 exhibiting the largest mean diameter ($p < 0.05$). Variations in stem diameter are attributed to genetic differences among cassava varieties. The study by Cassava Value Chain (2024) also reported a significant variation in stem diameter between dwarf and hybrid varieties, between varieties with larger and smaller vascular systems, and between those with high and low growth rates. A greater stem diameter indicates a higher concentration of carbohydrate reserves and high viability of the stem cuttings. Cassava plants originating from thicker stem cuttings were found to exhibit higher sprouting, survival, and growth rates compared to those originating from the thinner cuttings (Vigl and Rewald, 2014).

Stem cutting diameter ranged from 15.6 mm to 18.8 mm, with TARICASS4 exhibiting the largest mean diameter ($p < 0.05$). The differences in stem diameter among varieties are consistent with the findings of Cassava Value Chain (2024), who reported a significant variation in this trait attributed to differences in the genetic profile between dwarf and hybrid varieties, as well as between varieties with larger and smaller developed vascular systems, and varieties with high and low growth rates. A larger stem diameter indicates higher viability and sprouting potential, likely due to greater carbohydrate reserves compared to thinner cuttings. Similarly, Vigl and Rewald (2014) found that cassava plants derived from thicker cuttings exhibited higher sprouting, survival, and growth rates than those propagated from cuttings with smaller diameters.

The average moisture content of the stem cuttings was 57.7 %. This is a high moisture content that indicates high water retention capacity and adequate succulence of stem cuttings to support sprouting and plant resilience (Meibuko *et al.*, 2025). The variety Kiroba exhibited the highest moisture content, which was significantly greater compared to the other varieties ($p \leq 0.1$). This result aligns with the findings of Chen *et al.* (2024), who reported a significant variation in moisture content among cassava varieties. Such differences may be attributed to anatomical and physiological traits that influence moisture retention in cassava stems. For instance, varieties with thicker piths or more fibrous tissues tend to retain less moisture, and vice versa (Chen *et al.*, 2024).

Sprouting and shoot development

Sprouting duration and percentage varied significantly among varieties (Table 2). Sprouting occurred between 5 and 12 days after planting (DAP), with an average sprouting time of 7 DAP, which is earlier than the average sprouting time (10 to 15 DAP) reported by Schoffel *et al.* (2022) under field conditions. Similarly,

Table 2. Average sprouting performance of cassava stem cuttings across six varieties

Varieties	Sprouting percentage	Duration to sprouting of cuttings (days)
Chereko	100.00 a	8.67 a
Mkuranga1	100.00 a	6.33 bc
TARICASS4	100.00 a	5.67 c
Kiroba	97.20 a	7.00 b
Pwani	75.00 b	7.33 b
Kizimbani	66.70 b	9.00 a
Mean	89.81	7.33
LSD	9.874	1.086
CV	6.043	8.137
p value	< 0.001	0.00017

Note. Values sharing the same letters within a column do not differ significantly at the 5 % probability level ($p < 0.05$).

Baraka (2016) observed that sprouting under normal field conditions typically begins within 7–14 days, depending on the variety and the freshness of the cuttings.

Temperature and relative humidity of the growing area have a significant influence on cassava sprouting. Successful establishment requires high temperatures (25 °C – 35 °C) and relative humidity levels between 60 % and 80 % (Keating and Evenson, 1979). Kumaresan *et al.* (2019) reported effective sprouting under high humidity (above 85 %) combined with warm, controlled temperature conditions, while Akparobi *et al.* (2003) found that stem cuttings exhibited higher sprouting rates, accelerated growth, and increased biomass accumulation when grown under controlled ambient conditions with elevated temperatures. Likewise, Hillocks *et al.* (2002) highlighted that high temperature and humidity favor early sprouting in cassava. Therefore, the high temperature and humidity recorded inside the chamber likely contributed to the early sprouting observed in this study. The variety Kizimbani sprouted significantly later compared to the other varieties ($p \leq 0.001$), suggesting lower cutting viability, possibly influenced by variations in genetic profiles, nutrient composition, or node activity among varieties (Schoffel *et al.*, 2022; Meibuko *et al.*, 2025).

The average sprouting rate of the stem cuttings was 89.81 %. Sprouting was higher for most varieties, except for Pwani and Kizimbani, which showed less than 80 % (Table 2). These observations are consistent with the findings of Meibuko *et al.* (2025), who reported that TARICASS4 exhibited significantly higher sprouting than other varieties due to its superior genetic regenerative traits.

An average of five nodes per cutting, equivalent to 31 %, sprouted. Chereko cuttings showed a significantly higher mean number of nodes sprouted ($p \leq 0.01$) (Figure 4a-b). The failure of some cuttings to sprout may be attributed to genetic, nutritional, and physical factors, such as the presence of inactive nodes, mechanical or insect damage, and differences in nutritional content among varieties (Wang *et al.*, 2021).

Some nodes that sprouted failed to develop into shoots; on average, 2 nodes that sprouted per cutting developed into shoots. Most of the sprouted nodes in Kizimbani cuttings developed into shoots compared to those of other varieties (Figure 4c-d). This could be due to factors such as low nutrient composition, which may not support the growth of all sprouted nodes within a cutting. Although Kizimbani cuttings had fewer sprouted nodes, they exhibited the highest number of shoots developed per cutting. Wang *et al.* (2021) reported that numerous sprouted nodes within a cutting compete for nutrients, leading some of them to fail to form shoots. The number of shoots developed showed positive correlations with stem diameter ($r = 0.41$, $p = 0.10$), dry matter content ($r = 0.53$, $p = 0.05$), and the number of nodes per cutting ($r = 0.42$, $p = 0.1$). The findings of Ky-Dembele (2011) and Bridgemohan and Bridgemohan (2014) support these results, indicating that cassava cuttings with a greater number of nodes and higher initial carbohydrate reserves exhibit increased rooting and sprouting percentages.

The height of shoots developed varied significantly among varieties ($p < 0.001$) (Table 3). Shoots of Mkuranga1 and TARICASS4 exhibited the greatest plant height compared to the other varieties. This finding is consistent with the results of Phoncharoen *et al.* (2019) and Sarkiyayi and Agar (2010), who reported significant differences in plant height among the tested cassava genotypes. Similarly, Sukmadjaja and Widhiastuti (2011) observed significant variations in cassava shoot growth, with the Adira-4 variety showing the highest growth and regeneration rates. These differences could be attributed to variations in leaf area index, biomass accumulation, and storage root development among varieties (Matovu *et al.*, 2022). However, no significant differences ($p < 0.05$) were observed in plant vigor among the varieties.

Ratooning of shootlets

Over the four-month study period, eight ratooning cycles were conducted. The number of shootlets ratooned varied significantly among varieties, ratooning cycles, and their interactions ($p \leq 0.001$) (Figure 5). On average, 2.03 shootlets were ratooned per cutting in each cycle, and the number increased significantly with successive cycles. TARRICASS4 produced the highest number of shoots available for ratooning, followed by the Mkuranga1 and Chereko varieties (Figure 6). Differences in the number of ratoons among varieties may be attributed to the number and length of developing roots,

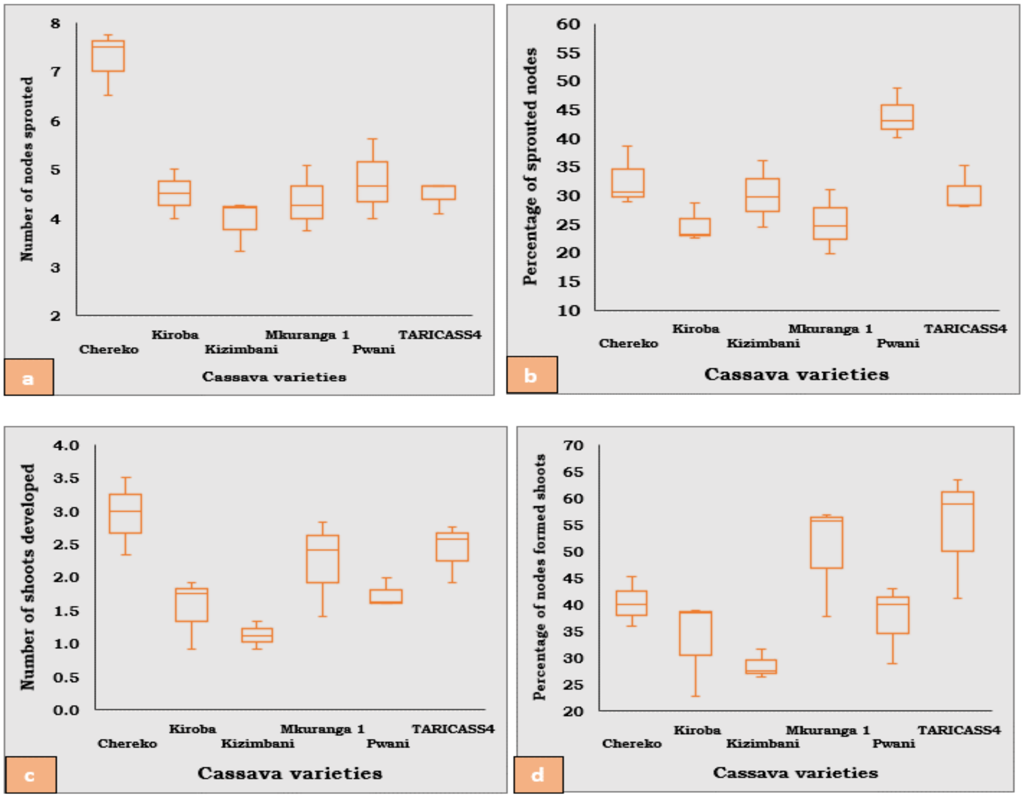

Figure 4. Average number of sprouted nodes (a), percentage of node sprouted (b), average number of shoots developed (c)and percentage of nodes that formed shoots (d) recorded across six cassava varieties.

Table 3. Average shoot growth parameters measured across six cassava varieties three weeks after planting

Varieties	Height of developed shoots (cm)	Shootlet vigor
Chereko	13.77 bc	4.67
Mkuranga1	16.03 a	4.67
TARICASS4	15.73 a	5.00
Kiroba	14.43 b	4.33
Pwani	13.23 c	4.67
Kizimbani	14.23 b	4.33
Mean	14.57	4.61
LSD	0.795	0.950
CV	2.998	11.326
p value	< 0.001	0.639

Note. Values sharing the same letter within a column do not differ significantly at the 5 % probability level ($p < 0.05$).

which penetrate deeper into the soil to absorb and accumulate more nutrients, thereby promoting faster regeneration (Pierret *et al.*, 2016; Hillocks *et al.*, 2002).

Root induction of shootlets

The duration of root formation, as well as the number and length of roots, varied significantly among varieties and root induction cycles ($p \leq 0.001$) (Table 4). Root formation in shootlets began 4–12 days after root induction. Most varieties, except Kizimbani and Chereko, developed roots within 7 days (Table 5). These results indicate that shootlet roots develop faster than those produced through tissue culture, which typically form within 2–3 weeks under standard conditions (Feyisa, 2021).

The average rooting percentage was 82 %. TARICASS4 shootlets showed a significantly higher rooting percentage than other varieties ($p \leq 0.001$) (Table 5). These findings are consistent with those of Dixon *et al.* (2005), who reported that root induction in the TME419 and IITA-TMS-I011368 cassava varieties occurs more rapidly than in other varieties.

The average number of roots developed per shootlet was 3, with Kizimbani shootlets producing significantly more roots than the other varieties (Table 5). The observed differences in root number among cassava varieties may be attributed to genetic variation (Silva *et al.*, 2016). The sixth and seventh ratooning cycles exhibited the lowest rooting percentage. The drop in temperature and rise in relative humidity inside the growth chambers, caused by external environmental changes such as cloudy conditions and heavy rainfall, persisted for five consecutive days, negatively affecting root formation between cycles. These conditions lead to rotting and the death of some shootlets, reducing multiplication efficiency (George *et al.*, 2008).

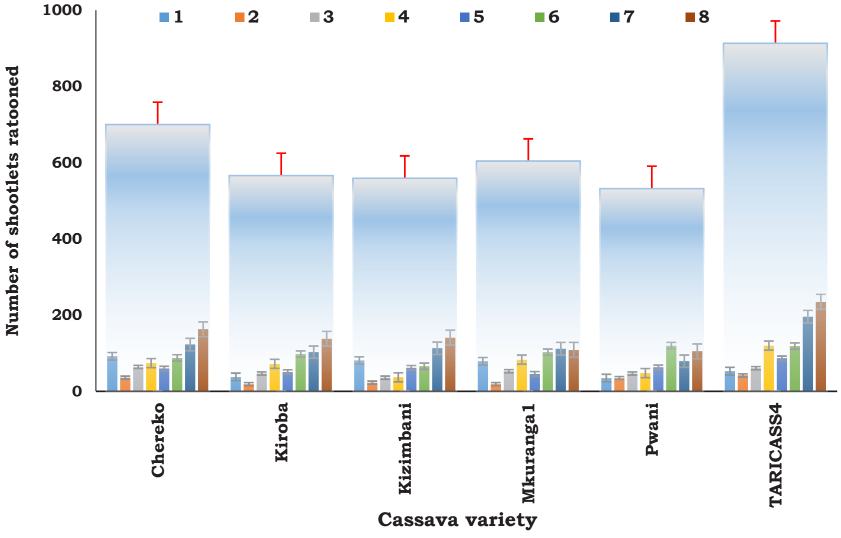

Figure 5. Cumulative number of shootlets per cassava variety across each ratooning cycle.

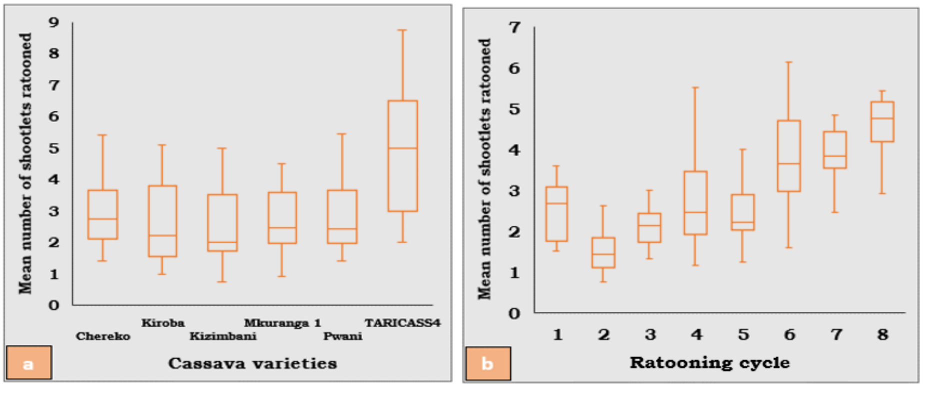

Figure 6. Mean number of shootlets ratooned per cutting across six cassava varieties (a) and over eight successive ratooning cycles (b).

Root length ranged from 5 cm to 13 cm, with TARICASS4 producing the longest roots among the varieties (Table 5). According to Matondo *et al.* (2025), the thickness of shootlets influences root length. Thicker shootlets develop longer roots, suggesting they possess greater surface area and nutrient reserves, which enhances rooting performance and development. Additionally, the number of nodes and the health status of the parent stock also influence root length (Muktar *et al.*, 2024).

Acclimatization of plantlets

The survival rate of shootlets during acclimatization varied significantly among varieties and acclimatization batches ($p < 0.001$), with an average of 97 % (Figure 7a). The development of numerous and longer roots was strongly correlated with shootlet survival ($r = 0.89$, $p = 0.001$), suggesting that rooting shootlets before planting is crucial to increase the shoot multiplication rate. These findings are consistent with those of Hillocks *et al.* (2002), who reported rapid secondary growth and a high survival rate in cassava plants, attributed to the formation of numerous fibrous roots. TARICASS4 exhibited a higher survival rate than the other varieties, possibly due to its greater ability to tolerate acclimation stress (Abah *et al.*, 2018).

Field establishment of plantlets

The survival rate of plantlets in the field varied significantly among varieties ($p \leq 0.01$). On average, 98.6 % of shootlets survived, with TARICASS4 exhibiting a higher survival rate than the other varieties (Figure 7a). More vigorous and well-rooted shootlets had a greater likelihood of survival than weaker ones. This observation is consistent with the findings of Ogero *et al.* (2023), who reported higher survival and growth rates in plants with well-developed root systems compared to those with limited root formation.

Table 4. ANOVA summary of cassava shootlet responses to root induction across six varieties over eight induction cycles

Source of variation	df	Mean duration to root formation	Percentage of rooted shootlets	df	Mean number of roots	Mean root length (cm)
Replication	2	25.87 ns	34.00 ns	2		0.75
Variety	5	104.79***	264.38***	5	1.022***	11.92***
Rooting cycle	7	205.25***	782.14***			
Variety*Rooting cycle	35	38.60**	39.41 ns			
Residual	94	19.33	42.97	10	0.333	0.84
Total	143			17		

Note. *** and ** denote significant differences at 0.001 and 0.05 probability levels, respectively. ns = not significantly different.

Table 5. Mean response values of cassava shootlets to root induction across six varieties over eight experimental batches

Variety	Duration to root formation	Percentage of rooted shootlets	Number of roots formed per cutting	Root length (cm)
Chereko	8.67 a	85.80 c	2.33 b	5.67 c
Kiroba	7.00 b	92.58 ab	2.33 b	8.33 b
Kizimbani	9.00 a	91.39 b	3.67 a	5.00 c
Mkuranga1	6.33 c	91.63 b	3.33 ab	8.00 b
Pwani	7.33 b	89.47 bc	2.33 b	9.33 ab
TARICASS4	5.67 c	95.77 a	2.67 ab	10.00 a
Mean	7.33	91.11	2.78	7.72
LSD	2.42	3.735	1.03	1.668
CV	4.86	7.153	20.78	11.875
p value	< 0.001	< 0.001	0.0519	0.00017

Note. Values sharing the same letters within a column do not differ significantly at the 5 % probability level ($p < 0.05$).

The height of plantlets established in the field ranged from 20 cm to 95 cm. Chereko plants exhibited significantly shorter heights than the other varieties ($p \leq 0.01$) (Figure 8a). The number of newly developed leaves also differed significantly among varieties ($p \leq 0.01$). Chereko produced more leaves than the other varieties (Figure 8b), indicating greater photosynthetic capacity, which contributes to a higher net production of cassava roots (Oliveira *et al.*, 2018).

Effectiveness of MSRT in the multiplication of the tested cassava varieties

Eight ratooning cycles were conducted within four months, which could result in a total of 24 cycles (n) within one year. The average number of shootlets produced per stem cutting in each ratooning cycle was 2.5. The average survival rates of shootlets during root induction, acclimatization, and field establishment were 91 %, 95 %, and 99 %, respectively. Based on these results, the multiplication result showed that one cassava cutting produced an average of 17 plants within four months and 51 plants per year (Figure 10). Using this multiplication rate, one bundle of fifty cassava stems, equivalent to 250 cuttings, could yield approximately 12 840 plants in a year. This production capacity would be sufficient to establish over 1.2 hectares of cassava field at a spacing of 1 m x 1 m.

The multiplication rate varied significantly among cassava varieties ($p \leq 0.001$). TARICASS4 exhibited the highest rate, whereas Mkuranga1 showed the lowest compared to the other varieties (Figure 9). The observed differences in cassava plantlet production among genotypes may be attributed to genetic factors that influence how each variety responds to the growing environment (Aladele and Kuta, 2010). Multilinear correlation analysis indicated that cassava plantlet production using MSRT technology was significantly correlated with several factors, including the number of roots ($r = 0.51$, $p = 0.001$), plant vigor ($r = 0.54$, $p = 0.001$), and the survival rate of shootlets during root induction ($r = 0.51$, $p = 0.001$), acclimatization ($r = 0.34$, $p = 0.001$), and field establishment ($r = 0.36$, $p = 0.001$).

Conclusion

Multiple Shoot Removal Technology (MSRT) enhances seed multiplication in vegetatively propagated crops by utilizing numerous shoots developed from a single plant to produce uniform, high-quality planting materials under natural and hygienic conditions. In this study, this technology significantly increased cassava seed multiplication ratio by approximately fivefold compared to the traditional method ($p \leq 0.001$). However, the response of the varieties to seed multiplication differed significantly ($p \leq 0.001$), ranging from 1:44 for Kizimbani to 1:80 for TARICASS4. The multiplication efficiency of MSRT was positively correlated with the quantity of shootlets generated through successive ratooning and their survival rates across the multiplication stages. The multiplication performance of each variety depended on its ability to develop numerous shoots, maintain high growth and regeneration rates, achieve strong rooting percentages, produce a considerable number and

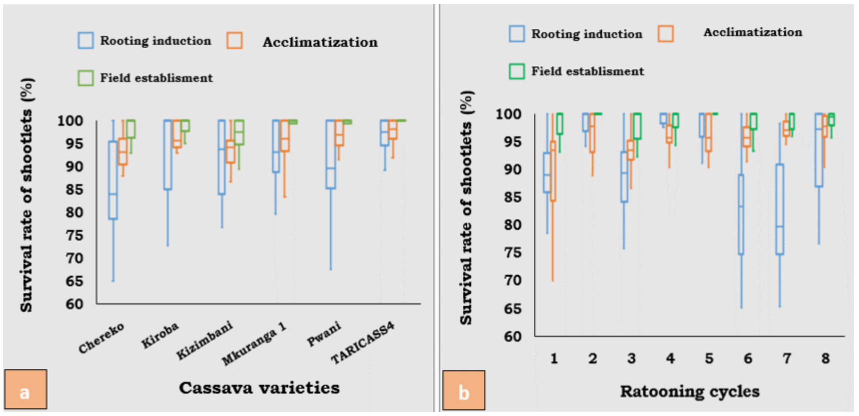

Figure 7. Average shootlet survival rates during root induction, acclimatization, and field establishment across six cassava varieties (a) over eight acclimatization cycles (b).

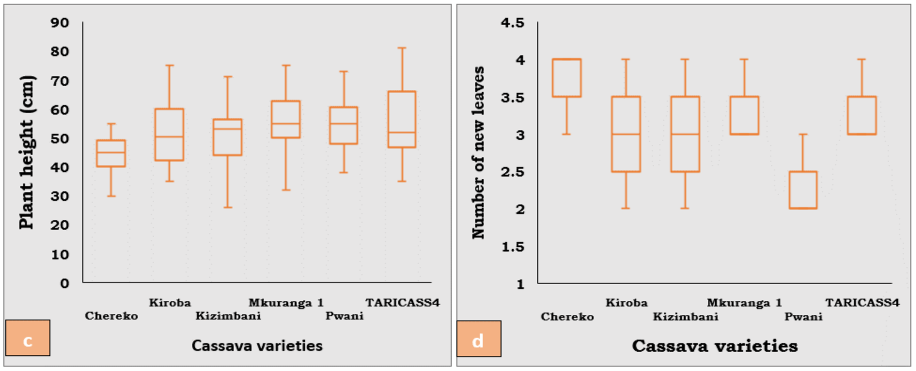

Figure 8. Average plant height and number of newly developed leaves of six cassava varieties at 2 months after planting (MAP) of plantlets.

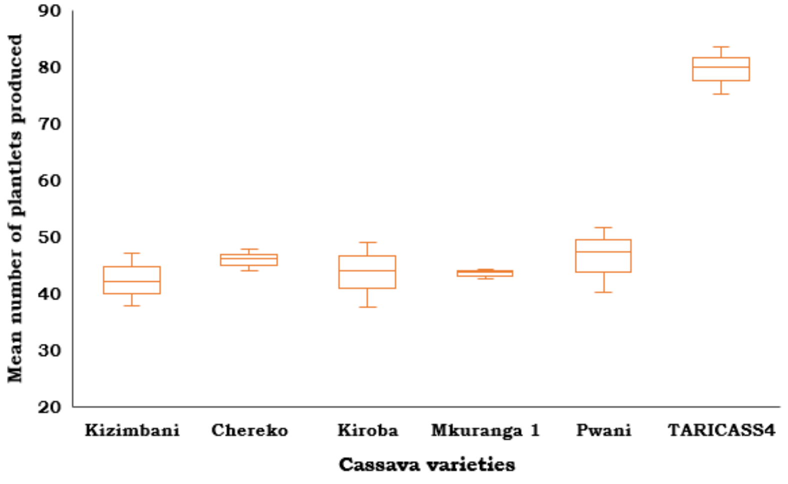

Figure 9. Average number of plantlets produced within four months by six cassava varieties.

i) The estimated number of plants or plantlets generated per cutting within a four-month period is as follows:

y = 2.5 x 8 x 1 x 0.91 x 0.95 x 0.99 = 17 plants/plantlets

ii) The projected annual output of plants or plantlets per cassava cutting is as follows:

y = 2.5 x 24 x 1 x 0.91 x 0.95 x 0.99 = 51 plants/plantlets

Figure 10. Calculation used to estimate the number of plants or plantlets produced per cutting within four months (i) and their projected annual production (ii).

length of roots, and ensure high shootlet survival. Based on these findings, MSRT is recommended as an effective approach for the rapid multiplication of cassava planting material to accelerate farmers' access to improved commercial cassava varieties in Tanzania and other cassava regions worldwide.

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