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RESEARCH ARTICLE

Storage root production of Cassava (*Manihot esculenta* Crantz) as affected by number of nodes per cutting and de-budding of axillary buds under container gardening in the Wet Zone of Sri Lanka

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Abstract: The present study was conducted to investigate the effect of the number of nodes per cutting and the de-budding of axillary buds on the growth and yield of cassava (*Manihot esculenta* Crantz) in container gardening. This study involves two sub-experiments for destructive sampling at three and six months after planting. There were ten treatments (T1-T10) according to the number of nodes (3, 5 & 7 per cutting) removal of axillary buds or de-budding procedure. Each treatment with three replicates was randomly allocated into a complete randomized block design using the cassava variety *Krikawadi*. There was a significant variation on the growth and yield performances of cassava among different treatments. The number, length, and width of the storage roots, fresh and dry weight of storage roots, and above-ground biomass at three and six months after planting were significantly different among treatments. Despite the treatments, storage roots increased their diameter, but not the length six months after planting. At the end of the experiment, the fresh and dry weight of storage roots, root weight ratio, and root to shoot ratio were greater in T7 which was 7-nodded cuttings without the de-budding procedure. Therefore, it is concluded that 7-nodded cuttings without performing de-budding procedures could produce optimum yield of storage roots under container gardening in the Wet Zone of Sri Lanka.

Keywords: *Axillary bud, Cassava, container gardening, de-budding, storage roots*

Introduction

By encouraging sustainable farming methods, it is crucial to balance the supply and demand of food to guarantee food security and end hunger. Food demand can be greater than the supply due to limited resource availability for crop production and increasing global population (Bahar et al., 2020). Balancing the demand for food with environmental sustainability, efficient production methods, and equitable distribution remains a complex challenge. Hence, potential efforts are required to enhance global crop productivity sustainably. As urbanization increases and arable land becomes limited, non-traditional cultivation methods such as container gardening are becoming important for sustaining crop production in urban and peri-urban areas. Cassava (*Manihot esculenta*) is a perennial (Parmar et al., 2017) and dynamic staple crop in tropical and sub-tropical areas having starchy roots, originating from South America (El-Sharkawy, 2003). Cassava is well known for its ability to withstand in suboptimal soils and diverse and adverse climatic conditions with the lowest influence on yield reduction (Howeler, 2014). Nassar,(2004) reported that over 700 million people rely on cassava as a primary source of energy while making cassava as the most significant crop in the tropics.

Cassava could be identified as a potential crop to face critical challenges of climate change scenarios at

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present and future due to its ability to resist heat and drought stresses (Carluccio et al., 2022). Cassava is mainly propagated through woody stem cuttings collected from the previous growing cycle (Chaweewan and Taylor, 2015). Production of economically important yield of cassava, storage roots, is influenced by various agronomic practices such as the number of nodes per cutting and the de-budding of axillary buds in the cutting. Usually, new shoots and roots are formed from nodes, and therefore nodes are considered as critical growth points of cassava. On the other hand, vigour of the plant and the successful establishment of the crop may depend on the number of nodes per cutting hence affect directly on the yield of storage roots (Ceballos et al., 2004). According to Remison et al.,(2015), planting material requirement for a large-scale plantation of cassava can be achieved by reducing the number of nodes per cutting which used as a propagation material. However, the number of buds on cassava stem cuttings play a dynamic role in the initiation of new shoots and storage roots after establishment. (Prasitsarn et al., 2018) stated that, farmers in northeastern Thailand increase storage root yield of cassava by removing the buds from the part of cuttings that is buried in the ground. Root initiation from a stem cutting in cassava is a natural process that involves the activation of dormant buds and the formation of adventitious roots. Types of cassava roots emergence from stem cuttings could be either fibrous roots or storage. The fibrous roots facilitate nutrient uptake, while the storage roots are the edible part of the plant and are harvested for various culinary uses. Eight weeks after planting, transcription profiling of fibrous, intermediate and storage roots of cassava can be observed (Sojikul et al., 2015) .

However, despite the importance of cassava, limited research evidence is available on its growth specially under container grading. The present study investigates the influence of two critical agronomic practices; the number of nodes per cutting and the removal of axillary buds (de-budding) on the storage root production of cassava in container gardening. By exploring the importance of container gardening with cassava, this study aims to improve techniques of cultivation and yield, particularly in limited growing conditions in container gardening.

Methodology

The present study was conducted at the Faculty of Agriculture, University of Ruhuna, Sri Lanka from June to December 2022. The area is in the Low Country Wet Zone (WL2) and receives an annual rainfall of about 2500 mm. The daytime temperature ranged between 26°C to 30°C while the relative humidity was 70% to 85%. Day length at the experimental site was 12/12 hours while light intensity was in between 45,000 to 180,000 Lux. The present study comprised two sub-experiments that were carried out in the open field using containers; sub-experiments 01 & 02 which were harvested at three and six months after establishment, respectively. Each sub-experiment was comprised of ten pre-determined treatments (Figure 1). This method aids in comprehending both the overall growth and yield as well as the variations in these parameters at two stages of the production life cycle of the crop. Each experiment was established in poly sack bags of 60 cm x 45 cm, filled with the potting mixture of topsoil and compost in 1:1 ratio (v/v). All containers were filled with 40 liters of potting mixture and kept in the open field. A Randomized Complete Block Design was used to set up the experiments due to the variation of light intensity at the experiment site. *Kirikawadi,* a locally grown, improved cassava variety reported high yield and acceptable horticultural qualities and recommended by the Horticultural Crop Research and Development Institute (HORDI, Gannoruwa), was used for the study due to its short crop duration (6 months for maturity). The disease-free hardwood stems (Adu, 2020) of cassava with equal intermodal length and diameter were selected for the study. Stem cuttings were cut into pieces having 3, 5, and 7 buds. A sharp knife was used to practice the de-budding technique to avoid possible damage to the stem. A single cutting per container was established with a 45-degree angle (slanting position) to the soil surface (Adu, 2020). During the planting, a single bud per cutting was kept above the ground in every treatment to ensure successful bud sprouting. The plants were irrigated twice a week, and weeds were removed manually. Fertilizer was applied according to the recommendation of the Department of Agriculture (DOA; Department of Agriculture, Sri Lanka). Spacing was optimized to facilitate better growth by 50 cm x 50 cm to avoid mutual shading after one month of planting. All agronomic practices were done following the recommendations given by the DOA.

Data Collection

The time taken for bud sprouting of the sub-experiment 01 was recorded two weeks after planting. The number of shoots that had arisen from each cutting of all treatments of the sub-experiment 01 was recorded after six weeks of planting. Destructive sampling was done to assess the number of root whorls and storage roots, length and diameter of storage roots, fresh and dry weight of storage roots, and fresh and dry above-ground biomass after three months of planting in the sub-experiment 01. Then, above-ground plant parts and storage roots were oven-dried at 80°C for three days to obtain dry weight.

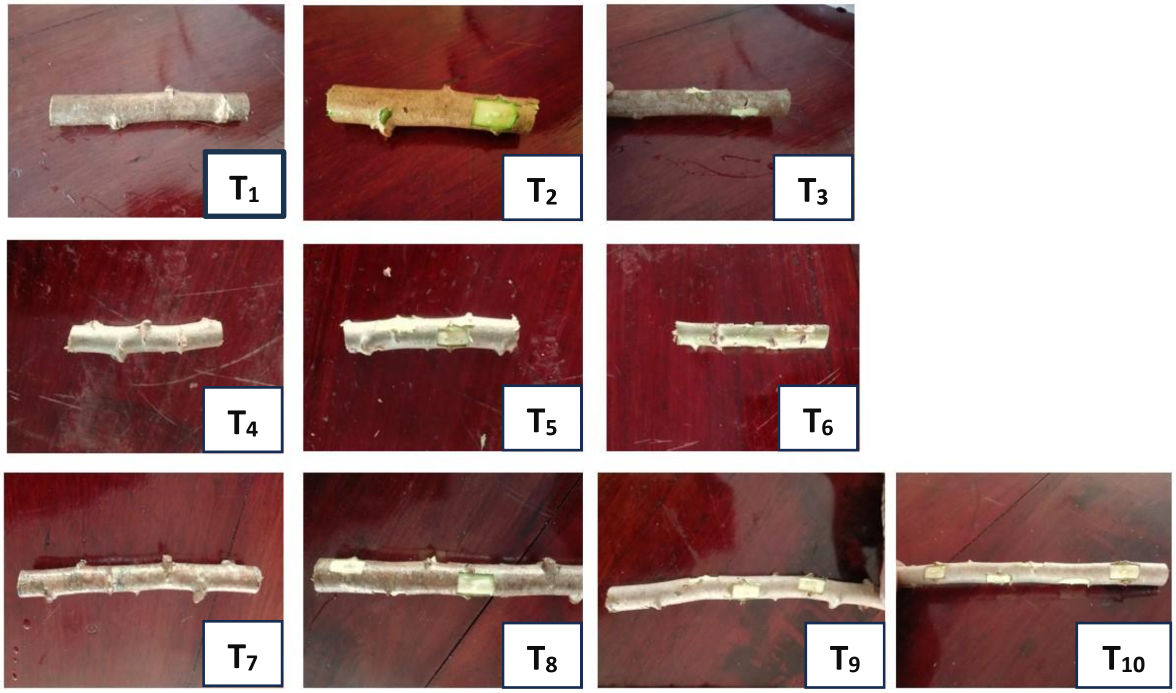

Figure 1: Treatments of the study (T_1: 3-node cutting without removal of buds, T_2: 3-node cutting with one bud removed, T_3: 3-node cutting with two buds removed, T_4: 5-node cutting without removal of buds, T_5: 5-node cutting with 3 buds removed, T_6: 5-node cutting with 4 buds removed, T_7: 7-node cutting without removal of buds, T_8: 7-node cutting with 4 buds removed, T_9: 7-node cutting with 5 buds removed and T_{10}: 7-node cutting with 6 buds removed)

Six months after planting, all experimental units of sub-experiment 02 were examined destructively. The number of root whorls, length and diameter of the storage roots, fresh weight of storage roots and above-ground biomass, and dry weight of storage roots and above-ground biomass were recorded. The root weight ratio (RWR; Equation 1), root shoot ratio (RSR; Equation 2) and the relative increment of the length (RIL, Equation 3) and relative increment of diameter (RID, Equation 4) of the storage roots were calculated based on the primary data. The percentage change in cassava root diameter and length during a given period is known as the relative increment of diameter and length, respectively. Relative increments of diameter and length were considered as indicators for evaluating the expanding potential of the roots within 3 months.

$$RWR = \frac{DRy\ weight\ of\ storage\ Root}{Total\ plant\ dry\ biomass} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{ Equation 1}$$

$$RSR = \frac{DRy\ weight\ of\ storage\ Root}{Above\ Ground\ dry\ biomass} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{ Equation 2}$$

$$RIL = \frac{(Length\ at\ 6\ MAP - Length\ at\ 3\ MAP)}{Length\ at\ 3\ MAP}\ x\ 100 \ \ldots\ldots\ldots\ldots\text{Equation3}$$

$$RID = \frac{Diameter\ at\ 6\ MAP - Diameter\ at\ 3\ MAP}{Diameter\ at\ 3\ MAP}\ x\ 100 \ldots\ldots\ldots\ \text{Equation4}$$

Where, MAP denotes 'months after planting'

Data analysis

Data that were collected under two sub-experiments were analyzed using Minitab software by analysis of variance (ANOVA). The Duncan's Multiple Range Test (DMRT) was used to separate treatment means at 5% significance level. Non-normal data such as the number of root whorls per plant and the number of storage roots per plant were transformed by log transformation technique followed by ANOVA. MS Excell 365 was used to present descriptive data by means of graphs.

Results and Discussion

According to the results of the sub-experiment 01, the time taken to sprout axillary buds and the number of shoots that emerged per cutting were not significantly different among treatments. All cuttings that received different treatments produced shoots within a one-week time. Similarly, the number of shoots per cutting did not vary among the treatments. According to Remison et al.,(2015) the number of branches produced per cutting of cassava in a polybag experiment was unaffected by the length of the cuttings. Further, the size of stem cuttings at the beginning of growth had no impact on dry matter partitioned to the roots. In the present experiment, removal of axillary buds or de-budding practice did not influence the number of shoots that emerged from a cutting (r = 0.2, $p > 0.05$).

The number of root whorls that emerged from cuttings of sub-experiment 01 varied significantly ($p < 0.05$) among treatments (Fig. 2). The number of root whorls that emerged from the cutting increased when increasing the number of nodes per cutting. According to Prasitsarn et al.,(2018), when the length of the cuttings was shorter than 15 cm, cassava plants produced more storage roots per plant than the cuttings longer than 30 cm.

The number of storage roots per cutting was significantly different among treatments ($p < 0.05$) where T1 (22.0), T2 (15.0), T4 (15.7), T7 (16.7), and T8 (15.3) showed better performances than other treatments. The T3 (11.3), T5 (8.7), T6 (8.7), and T10 (10.3) recorded the lowest number of storage roots per cutting (Fig. 3). Hartati et al.,(2021) have reported that calluses developed at the base of stem cuttings shortly after being planted. Diverging from the calluses that formed at the base of the cassava cuttings were many roots or tubers. El-Sharkawy,(2003), mentioned that during the first two months of life, the cassava plant largely develops branches and a fine root structure. Many cultivars have shown starch deposition 25–40 days after planting, and the formation of storage roots begins with secondary growth in several fibrous roots. The growth and appearance of the storage roots of cassava in sub experiment 01 at three months after planting is shown in Figure 4.

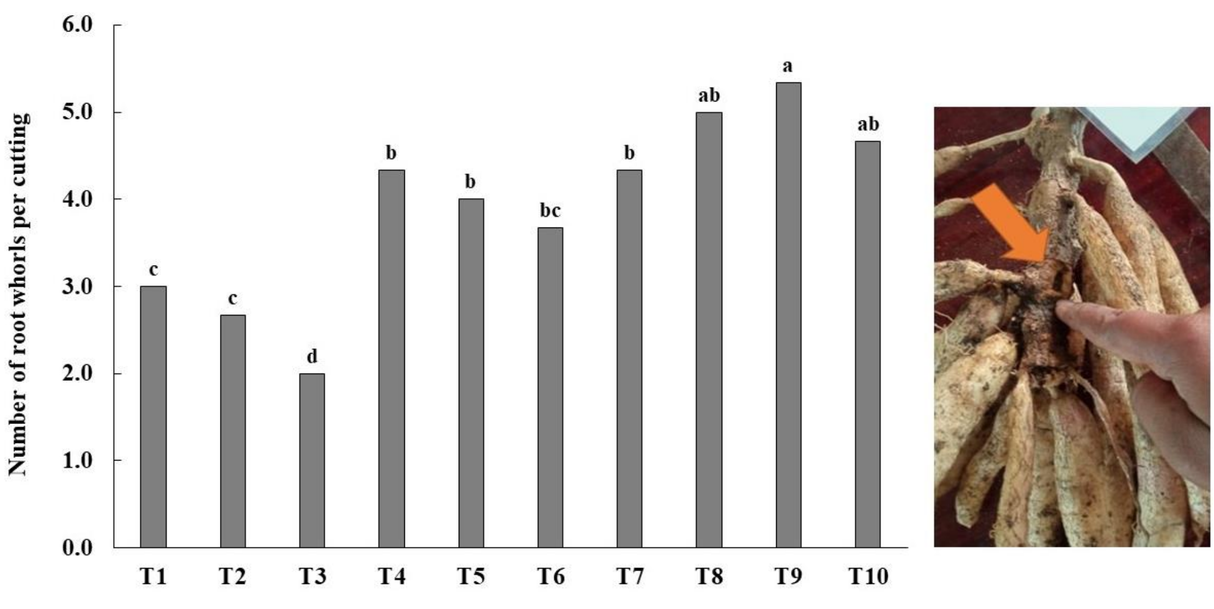

Figure 2.: Number of storage root whorls per cutting in the sub-experiment 1. Means are presented in bars with different letters are statistically different from each other at 5% probability level as determined by DMRT

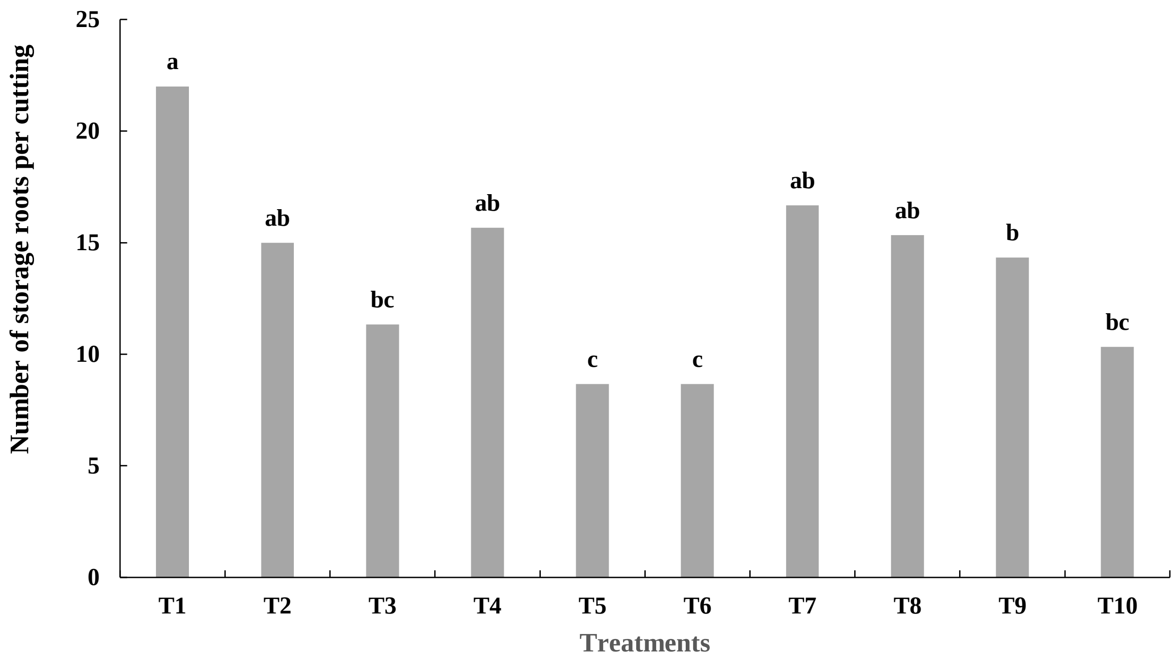

Figure 3: Number of storage root whorls per cutting in the sub-experiment 01. Means presented in bars with different letters are statistically different from each other at 5% probability level as determined by DMRT

Figure 4: Effect of different treatments on growth and the appearance of the storage roots of cassava at three months after planting in sub-experiment 01.

Table 1: Length and diameter of storage tuber roots in sub-experiments 01 and 02 at three and six months after planting and relative increment of length and diameter of storage roots Means with different letters are statistically different from each other at 5% probability level as determined by DMRT. NS denoted as "Not Significant"

Treatments	**Sub-experiment 01 (3 months after planting)**		**Sub-experiment 02 (6 months after planting)**		**Relative increment of length (%)**	**Relative increment of diameter (%)**
	Tuber length (cm)	**Tuber diameter (mm)**	**Tuber length (cm)**	**Tuber diameter (mm)**		
T_1	16.45^{d}	17.1^{bc}	17.20^{ab}	42.5^{b}	5^{a}	101^{b}
T_2	16.95^{d}	18.6^{bc}	17.82^{ab}	38.9^{bc}	5^{a}	118^{b}
T_3	19.73^{ab}	18.7^{bc}	20.60^{a}	49.5^{a}	4^{a}	82^{c}
T_4	18.03^{abcd}	16.0^{bc}	19.11^{a}	34.9^{c}	5^{a}	84^{c}
T_5	16.96^{d}	16.3^{bc}	17.91^{ab}	35.4^{c}	6^{a}	98^{b}
T_6	20.10^{a}	20.5^{ab}	21.11^{a}	42.4^{b}	5^{a}	101^{b}
T_7	18.42^{abcd}	17.6^{b}c	19.20^{a}	37.9^{c}	4^{a}	97^{b}
T_8	17.43^{cd}	17.6^{bc}	18.25^{ab}	35.4^{c}	5^{a}	94^{b}
T_9	17.83^{bcd}	14.8^{c}	18.63^{ab}	30.2^{d}	4^{a}	62^{d}
T_{10}	14.54^{e}	24.2^{a}	15.54^{c}	52.3^{a}	7^{a}	155^{a}
P	<0.01	<0.05	<0.05	<0.05	*NS*	<0.001

The average length and diameter of the storage root were significantly varied ($P< 0.05$) among treatments in both sub-experiments (Table 1). The longest storage roots were produced in T6 (20.1 cm), T3 (19.7 cm), T7 (18.4 cm) and T4 (18.0 cm) treatments. The significantly greater diameter of the storage root was observed in T10 (24.2 mm) and T6 (20.5 mm) treatments (Table 1) three months after planting.

The length of the storage roots was significantly different among treatments after six months of planting in sub-experiment 02 (Table 1). However, the relative increment of length of each treatment was not significantly different among treatments (Table 1) which were in a range of 4 - 7%. Assessing the relative dimensions of cassava roots is important for assuring ideal growth, performing overall productivity of cassava cultivation, and improving cassava output and food security. Hence the rate of root bulking has a significant influence on these treatments. In this study, the relative increment of the length of storage roots may be restricted by the volume and space of the container. Furthermore, the limited length increment could be due to air-root pruning of storage roots.

The effect of treatments on diameter and relative increment of the diameter of the storage root was significant at six months after planting. The greatest relative increment of diameter was recorded in T10 (155%) where 7-node cutting was used without 6 axillary buds and the lowest value in T9 (62%) where 7-node cutting was used without 5 buds (Table 1).

According to the results, it can be suggested that a high relative increment of the diameter of storage roots may be associated with the limited length of the roots. Assimilated food of the plant through photosynthesis should be stored in the roots as those are the primary sink of cassava. Bridgemohan and Bridgemohan and Bridgemohan,(2014), reported that the initial length of the stem nodal cutting impacts the output of crop as storage roots, by balancing assimilation production and demand. Howeler,(2014) has stated that most cassava fibrous roots are found in the top 20 cm of the soil, although some can grow up to a depth of one meter and others can grow 1-2 meters sideways. In the present study pots were used instead of field planting and the length of roots could be restricted in all plants due to air pruning. Izumi et al.,(1999) revealed that when tuber bulking started, the number and length of axile and lateral roots started to decline, and similarly the drop in lateral root length persisted in all treatments (Table 1).

In sub-experiment 01, treatments of the study had a significant impact ($p < 0.05$) on fresh weight and dry weight of storage roots ($p < 0.01$) (Table 2). According to the results, greater fresh and dry storage root weight was recorded in T1, T3, T4, T7, and T10 treatments (Table 2). There was no significant relationship between either storage root weight and number of nodes per cutting ($r = 0.14$, $p > 0.05$) or storage root weight and the number of axillary bud removal of the cutting ($r = 0.38$, $p > 0.05$) in the present experiment at three months after planting. The above-ground fresh and dry biomass per cutting ($p < 0.01$) was significantly different among treatments (Table 2).

Table 2: Fresh and dry weight of storage roots and fresh and dry weight of above-ground biomass at three months after planting in the sub-experiment 01 Means with different letters are statistically different from each other at 5% probability level as determined by DMRT

Treatments	Fresh weight of storage roots (g)	Dry weight of storage roots (g)	Above-ground fresh biomass (g)	Above-ground dry biomass (g)
T_1	609.94^{ab}	197.10^{abc}	474.28^{a}	154.77^{a}
T_2	528.55^{bc}	171.23^{bcd}	368.28^{bc}	108.96^{cd}
T_3	559.46^{abc}	180.72^{abcd}	348.36^{c}	97.08^{d}
T_4	608.81^{ab}	203.41^{ab}	463.85^{ab}	149.06^{ab}
T_5	453.54^{c}	134.94^{d}	358.50^{c}	105.21^{cd}
T_6	466.91^{bc}	135.91^{d}	380.64^{abc}	119.25^{bcd}
T_7	537.98^{abc}	227.71^{a}	424.15^{abc}	142.84^{ab}
T_8	519.54^{bc}	166.09^{bc}	428.07^{abc}	135.70^{abc}
T_9	446.49^{c}	154.09^{cd}	400.4^{abc}	108.01^{cd}
T_{10}	682.39^{a}	192.28^{abc}	443.59^{abc}	131.6^{abc}
P value	<0.05	<0.01	<0.01	<0.01

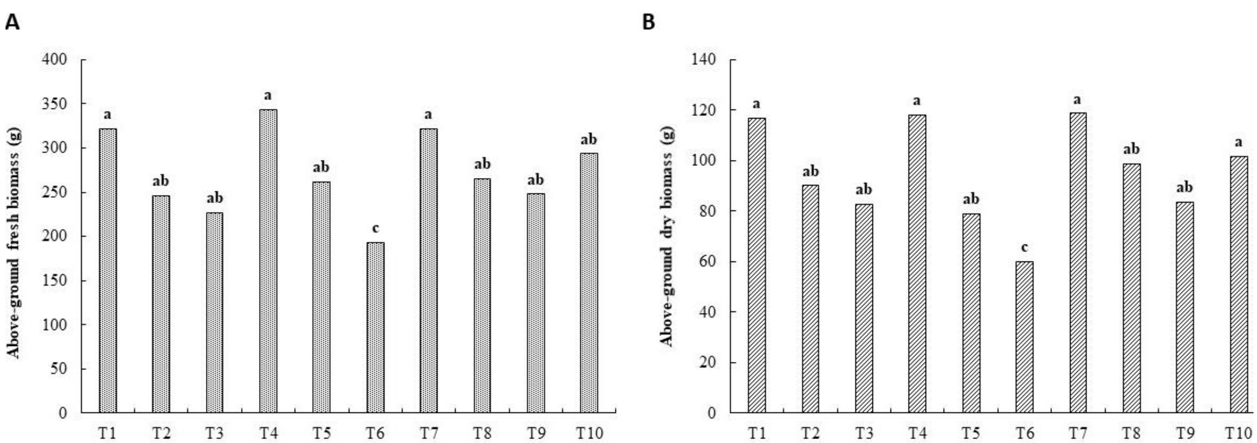

Figure 5: Dry matter assimilation on above-ground as (A) fresh biomass (B) dry biomass of sub-experiment 02. Bars with different letters are statistically different from each other at 5% probability level as determined by DMRT.

According to the results of sub-experiment 02 harvested six months after planting, the above-ground fresh and dry biomass significantly differed among treatments ($p < 0.001$, Figure 5). The lowest above-ground fresh biomass was recorded in T6 where five-node cutting that removed four buds was used (Fig. 5A). A similar trend was observed in dry biomass production of above-ground plant parts (Fig. 5B) at six months after plating in the sub-experiment two. However, Murray and Cohen,(2021) have stated that the two-node cuttings exhibited a notable increase in internode volume and fresh mass, while maintaining identical internode width and density. Cock et al.,(1979) explained that only assimilates remaining after fulfilling the growth requirements of plants were given to the storage roots. However, in this pot experiment, the number of shoots and canopies are approximately similar, meanwhile, the sources are nearly the same where the primary sinks are not equal. (Bridgemohan and Bridgemohan, 2014) stated that initial strength due to its dry matter content, the three-node fully grown cassava stems illustrated better performances than a single-node cutting. This had a

Table 3: Fresh weight of storage root, dry weight of storage roots, root weight ratio and root shoot ratio at 180 days after planting in the sub-experiment 02 Means with different letters are statistically different from each other at 5% probability level as determined by DMRT

Treatments	Fresh weight of storage roots (g)	Dry weight of storage roots (g)	Root weight ratio	Root shoot ratio
T_1	1370.9^{b}	301.5^{b}	0.72^{d}	2.58^{d}
T_2	1205.9^{c}	320.1^{b}	0.78^{b}	3.55^{b}
T_3	1230.6^{c}	307.7^{b}	0.79^{b}	3.72^{b}
T_4	1379.4^{b}	298.3^{b}	0.72^{d}	2.52^{d}
T_5	1280.2^{c}	273.5^{b}	0.78^{b}	3.47^{b}
T_6	900.7^{d}	210.8^{c}	0.78^{b}	3.52^{b}
T_7	1540.8^{a}	525.8^{a}	0.83^{a}	4.84^{a}
T_8	1010.4^{cd}	263.9^{b}	0.73^{bc}	2.68^{d}
T_9	1158.1^{cd}	260.0^{b}	0.76^{bc}	3.11^{c}
T_{10}	1225.4^{c}	363.6^{b}	0.78^{b}	3.58^{b}
P value	<0.01	<0.01	<0.01	<0.01

major impact on the amount of dry matter assimilation in storage roots and the yield of harvestable crops.

In sub-experiment 02, the treatment effect on the fresh weight of the storage roots was significant ($p < 0.01$, Table 3). The highest fresh weight of storage root was reported in T7 (1540.8 g) where 7-node cuttings were used without applying the de-budding procedure while T6 treatment where 5-node cutting was used with 4 buds removed reported the lowest value (900.7 g) (Table 3). Similarly, T7 was recorded as the highest dry weight of the storage roots (525.8 g), and the lowest value was observed in T6 (210.8 g).

Root weight ratio varied significantly among treatments, where this ratio was in the range of 0.72 to 0.83 (Table 3). The greatest value of 0.83 was observed in the T7 treatment where 7-node cuttings were used without applying the de-budding procedure while the lowest value of 0.72 was in T1 and T4 (P<0.01). Therefore, it can be suggested that most of the storage root weight per unit of total plant weight was produced by T7 treatment. The root weight ratio is an important indicator to evaluate the resource use efficiency of root crops as cassava storage roots are an economically important part of the plant. Prasitsarn et al.,(2018) reported a significant genetic variation in root weight ratio on storage root production and overall yield of cassava. Further, Ntawuruhunga et al.,(2001) reported that yield components of storage root number, storage root weight, storage root girth and total leaf area explained 72% of the variation in fresh yield of storage roots. In general, there is a positive relationship between the weight of the storage roots and the root weight ratio of root crops up to a certain extent. Beyond that level, various other factors such as resource availability of plant growth, crop management, agronomic practices, and environmental factors could influence the root weight ratio.

The root shoot ratio was also significantly influenced by the treatments ($p < 0.01$) where the highest value of 4.84 was recorded by T7 treatment. The lowest values were observed in T1, T4 and T8 treatments (Table 3). According to Teerawanichpan et al.,(2008) older fibrous roots (those that are three or six months old) or fibrous roots that are starting to accumulate starch (about two months after planting) can be identified as the intermediate stage between fibrous roots and storage roots. Moreover, a correlation analysis showed a significant relationship between above-ground fresh biomass production and the fresh weight of the storage roots (r = 0.61, $p < 0.05$). According to Figure 6, approximately 61% variation in fresh weights of storage root is explained by the variation in fresh weight of the above-ground biomass. The rest of the variation in the fresh weight of storage roots may be associated with the variety, climatic factors, and the source-sink relationship.

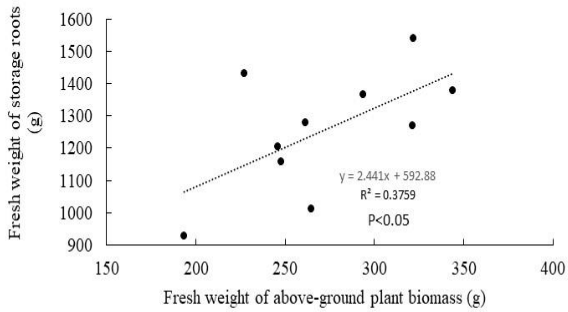

Figure 6: Relationship between fresh weight of the above-ground plant biomass and fresh weight of storage roots of sub-experiment 02

Varietal traits and planting techniques also had a significant impact on the root growth and development of cassava cultivars (Narmilan and Puvanitha, 2020) . In present study, a single variety (*Kirikawadi*) was used with different number of nodes per cutting and de-budding of axially buds. In the present study, increased number of root tubers resulted in increasing root tuber yield as number of root whorls and number of storage roots have enhanced after six months of planting. Remison et al.,(2015) pointed out that reducing the length of the cassava cuttings is one of the ways to decrease the amount of material availability for large-scale plantations. Appearance of the root system of cassava at six months after planting in sub-experiment 02 under different treatments was shown in figure 7.

Figure 7: Effect of different treatments on growth and the appearance of the storage roots of cassava at six months after planting in sub-experiment 02

The present study provides a basic knowledge of storage root development when changing the number of nodes and the de-budding technique. This is the first reported study regarding the de-budding practice while altering the number of nodes of the cutting of cassava variety *Kirikawadi* found in Sri Lanka.

Conclusion

The most important economically valuable parameters of the fresh and dry weight of storage roots were greater in the treatment (T7) where 7-node cuttings were used without applying the de-budding procedure after six months of planting. Therefore, additional efforts to practice de-budding procedures are not important to have a good quality yield of cassava under container gardening. Further, the length of storage roots was restricted by the air-pruning of the container and the limitation of the soil resources. Therefore, it can be concluded that seven nodded cuttings without removing axillary buds could be used to get the maximum yield of cassava variety *Kirikawadi* under container gardening in the low country Wet Zone of Sri Lanka. However, further studies are needed for firm recommendations.

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