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Production of *Coffea canephora* seedlings through cuttings in a nursery and hydroponics using different containers

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ABSTRACT

The production of seedlings is a determining factor for the establishment and success of the coffee plantation. The objective of this study was to evaluate the production of *Coffea canephora* seedlings by cuttings in a modified hydroponic system and in a conventional nursery, using different containers. At the end of the experiment, growth (height, stem diameter, total number of pairs of leaves, leaf area, root area, dry matter weight of leaves, stem and root), physiological (chlorophyll a, b and total and stomatal conductance) and anatomical (stomatal density, functionality and opening) characteristics were analyzed. For statistical analysis, a completely randomized design (CRD) was used, with five treatments and six replications, with ten plants per plot. Seedlings produced in a modified hydroponic system using 50- and 120-cm³ tubettes show better vegetative growth and physiological characteristics compared to those produced in a nursery. Seedling management in a modified hydroponic system using 120-cm³ tubettes provides greater cutting survival percentage, number of remaining leaves and emission of shoots. In nurseries, the use of polyethylene bags provides better seedling quality and survival in relation to the use of tubettes, regardless of volume.

Key words: Conilon coffee; anatomy; physiological characteristics; microscopy.

1 INTRODUCTION

Coffee is one of the most consumed beverages in the world, and the species *Coffea canephora* has great economic importance worldwide and nationally, being widely used in the soluble coffee industry and in blends with Arabica coffee. The interest in planting this coffee species has increased among growers and, consequently, the demand for seedlings for implantation and renewal of areas (Alves et al., 2023, Ribeiro et al., 2014).

Coffea canephora presents gametophytic self-incompatibility, a highly effective mechanism in the control of self-fertilization and in the crossing of related individuals, which induces allogamy in the plant, making it difficult to use seeds for its propagation. Thus, the production of seedlings by cuttings has been the main means of propagation of the species in the commercial production of seedlings, aiming to obtain uniform and productive varieties (Covre et al., 2015, Ferrão et al., 2017).

In the production process of *Coffea canephora* seedlings, either through sexual or asexual propagation, the substrate used in great majority consists of a mixture of subsurface soil (70%), cattle manure (30%) enriched with simple superphosphate and other fertilizers. Despite being efficient and providing high vigor to the seedlings, this substrate is not standardized and can carry pests, diseases and weeds. With the use of inert substrates, this sanitary problem is practically non-existent (Ferrão et al., 2017).

Another important factor to consider is that most seedlings are conducted in polyethylene bags which, despite being efficient and low-cost, use a very large volume of substrate, which makes filling and handling difficult, besides requiring large areas in nurseries.

Most seedlings are formed in nurseries, with a constant irrigation system, which results in high water consumption. Chalfun and Faquim (2008) developed a modified hydroponic system, in which a nutrient solution stays in a 'pool' in contact with the seedlings and circulates through the use of a motor pump system activated by a timer, which is connected to a reservoir with the nutrient solution. This system has been studied and has been successful in the production of seedlings of perennial species, such as citrus (Gomes et al., 2019) and pear (Souza et al., 2015). It has several advantages over the usual cropping system for these species, such as less time for seedling formation, better sanitary quality, in addition to lower water consumption.

For the production of clonal *Coffea canephora* seedlings, there are still no established methodologies (protocols) for the hydroponic system. Therefore, the objective of this study was to evaluate the production of *Coffea canephora* seedlings by cuttings in a modified hydroponic system and in a nursery (conventional), using different containers and substrates.

2 MATERIAL AND METHODS

The experiment was carried out in the Coffee Sector and in the Horticulture Sector, located in the Department of Agriculture of Universidade Federal de Lavras (UFLA), Lavras – MG, It was conducted in a completely randomized design, with six replications and ten plants per plot. Five treatments were evaluated for the production of clonal seedlings: modified hydroponic system (MHS) in 50 cm³ and 120 cm³ tubbette, nursery (N) with 50 cm³ and 120 cm³ tubes and nursery with polyethylene bags (PB) with dimensions 9 x 18 cm.

Matrix *Coffea canephora* plants 'Conilon 213' belonging to the germplasm bank of the Coffee Sector of UFLA, were selected to obtain clonal seedlings. The nodal segments were obtained from orthotropic branches, where the middle part was used for the production of cuttings, cut in bevels, in segments of approximately 5 cm, so as to contain a pair of leaves cut to one third of its area. Subsequently, the cuttings were immersed in a 0.05% sodium hypochlorite solution for ten minutes, washed in water and inserted into different containers and cultivation systems (Ferrão et al., 2017).

The seedling production process in the nursery, with polyethylene bags, the following mixture was used for each m^3 of substrate: 70% subsurface soil, 30% bovine manure, 2 kg of dolomitic limestone, 5 kg of simple superphosphate and 0.5 kg of sodium chloride potassium. In the case of the tubettes in nursery (50 and 120 cm^3), the commercial substrate Plantmax® was used, with the addition of the slow-release fertilizer Osmocote Plus®, which remained on a bench suspended 80 cm from the ground. For the control of solar radiation, a 50% shading net was used, and the plants were irrigated by a sprinkler in two watering shifts for 30 minutes a day. An average temperature of 28.7°C and 43.7% relative humidity, respectively, were recorded during the experiment.

For the production of seedlings in a modified hydroponic system, the cuttings were placed in 50- and 120-cm³ tubettes containing vermiculite (inert substrate). The methodology proposed by Chalfun and Faquin (2008) was used, conducted in the 'pool' system, with circulation of the nutrient solution, using 960g MaxSol F21, 720g calcium nitrate and 40g EDDHA iron chelate, diluted in 1000 L water in a reservoir. The solution circulated in the pools through a motor-pump set associated with the activation of a timer, lasting 15 minutes, four times a day. The excess of the nutrient solution in the 'pool' returned to the reservoir by gravity, through its own piping. Nutrient replacement in the nutrient solution occurred through the control of electrical conductivity, and it was adjusted with the addition of the macro-and micronutrient stock solution, prepared in accordance with the recommendations of the aforementioned authors. The pH of the nutrient solution was maintained between 5.5 and 6.5 and nutrient solution changes were made every 30 days. The average temperature and relative humidity during the experiment were 28.4°C and 41.5%, respectively.

Since the experiment was set, weekly evaluations were carried out to monitor seedling development, by measuring the number of remaining leaves, shoot number and cutting survival percentage.

The following evaluations were performed at 150 days after cuttings: total leaf number (TLN), total shoot number (TSN), number of plagiotropic branches (NPB), seedling height, mean shoot diameter (MSD), mean shoot length (MSL), number remaining leaves (NRL), cutting survival percentage (CSP), leaf (LDMW), stem (SDMW), root (RDMW) and total (TDMW) dry matter weight, total leaf area (TLA).

From the leaf area and dry matter weight data, the following characteristics were estimated: leaf area ratio (LAR), in $cm^2.g^{-1}$, also known as leaf area quotient, obtained through the ratio between total leaf area (TLA) and total dry matter weight (TDMW); specific leaf area (SLA), in $cm^2.g^{-1}$, which relates the surface to the dry matter weight of the leaf itself, obtained through the ratio of TLA by leaf dry matter weight LDMW; leaf weight ratio (LWR), in $g.g^{-1}$, obtained by the ratio of LDMW by TDMW; specific leaf matter (SLM), in $mg.cm^{-2}$, which is the ratio of LDMW and TLA.

The roots were analyzed by the SAFIRA software, 'Fiber and Root Analysis System', developed by Embrapa Instrumentação, where the cuttings were removed from the containers, carefully washed in water, positioned next to the scale (cm), on a black surface for contrast, and photographed with the aid of a professional camera. Subsequently, data on root volume (mm^3), area (mm^2), length (cm) and diameter (mm) were analyzed.

Contents of chlorophyll a, b and total were indirectly measured, obtained through readings taken on a leaf tissue using a portable meter clorofiLOG - CFL1030 (Falker automação agrícola), which provides values called Falker chlorophyll indices (FCI), proportional to chlorophyll absorbance (Barbieri Júnior et al., 2012).

Stomatal conductance (SC) ($\mu mol\ m^{-2}\ s^{-1}$) was obtained from the leaf vapor flow through the stomata to the external environment using a porometer (SC^{-1} Decagon Devices); readings were performed in the median region of the blade completely extended, between 8 a.m. and 10 a.m.

Anatomical evaluations were also performed, such as scanning electron microscopy (SEM), in which leaves were collected from coffee plant cuttings and fixed in Karnovsky solution for 24 hours, washed three times for 10 minutes in 0.05M cacodylate buffer, dehydrated in progressive acetone gradients (25, 50, 75, 90% for 10 minutes and at 100% three times of 10 minutes), taken to the critical point apparatus (Bal-Tec), metallized in a gold evaporator (Bal-Tec 050) and observed in a scanning electron microscope (Carl Zeiss LEO Evo40 XVP) from the Electron Microscopy and Ultrastructural Analysis Laboratory at UFLA.

The Image tool software was used to determine stomatal density (number of stomata per mm²), counting the number of stomata per area.

Energy dispersive x-ray microanalysis (EDX) was also performed. Readings of the chemical elements present in the samples were taken in percentage and mapping, indicating the location of these nutrients in the plant tissue. A Bruker x-ray energy dispersive detector was used, coupled to a scanning electron microscope (Carl Zeiss LEO Evo40 XVP) from the Electron Microscopy and Ultrastructural Analysis Laboratory of UFLA.

The data were submitted to normality and homogeneity tests; for analysis of variance, the statistical analysis software SISVAR® (Ferreira, 2011) was used and, for the grouping of means, the Scott-Knott test at 5% of significance was used.

3 RESULTS

It was observed that, from 35 DAC, there was a decrease in cutting survival percentage for all treatments and, for seedlings produced in MHS in 120-cm³ tubettes, lower losses were verified throughout the production process, followed by those produced in this system in smaller containers and in a nursery with polyethylene bags. Among the seedlings produced by the treatments carried out in a nursery, higher cutting survival percentage was observed using polyethylene bags. Seedlings produced in tubettes (50 or 120 cm^3) did not survive (Figure 1A, Table 1).

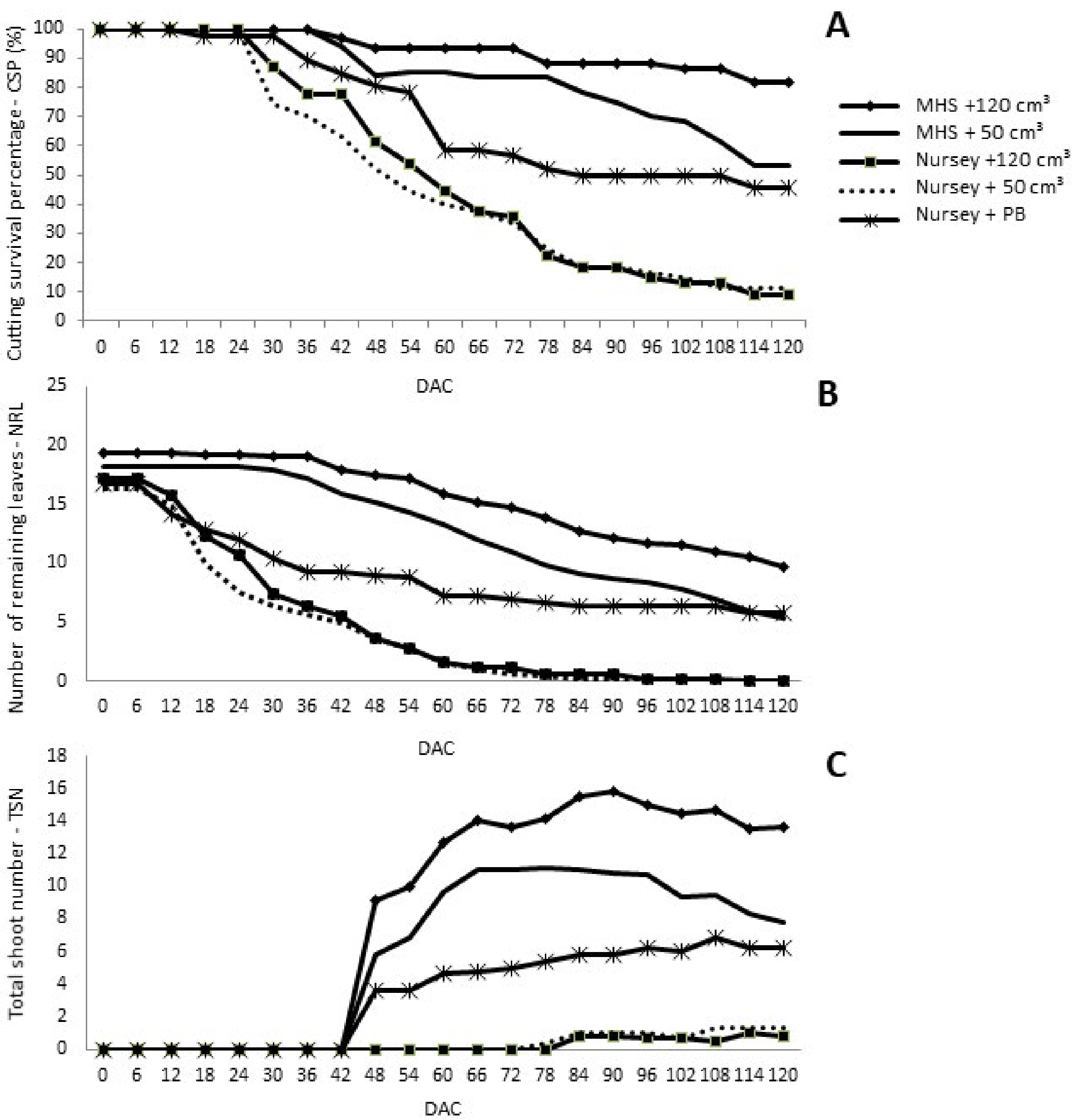

Figure 1: A: Cutting survival percentage - CSP, B: number of remaining leaves - NRL and C: total shoot number - TSN, evaluated for 120 days in the seedling production process by cutting of *Coffea canephora* in modified hydroponics (MHS) and nursery (N), in different containers (50-cm³ tubette - 50; 120-cm³ tubette - 120 and polyethylene bag - PB). DAC: Days after cutting.

Table 1: Growth characteristics, cutting survival percentage - CSP, number of remaining leaves - NRL, seedling height - SH , total leaf number - TLN, longest root length - LRL, number of plagiotropic branches - NPB, total shoot number - TSN, mean shoot length – MSL, mean shoot diameter - MSD, evaluated in *Coffea canephora* seedlings, produced by cuttings in modified hydroponics (MHS) and nursery (N), in different containers (50-cm³ tubette – T 50; 120-cm³ tubette – T 120 and polyethylene bag - PB).

Treatments	CS (%)	NRL	SH (cm)
MHS T 50	51.667 b	1.438 a	8.887 a
MHS T 120	75.000 a	1.527 a	7.733 a
N T 50	0.000 c	0.000 c	0.000 b
N T 120	0.000 c	0.000 c	0.000 b
N PB	42.000 b	1.040 b	7.443 a
	TLN	LRL (cm)	NPB
MHS T 50	8.860 a	33.205 a	2.235 a
MHS T 120	7.028 b	26.715 b	1.570 a
N T 50	0.000 d	0.000 d	0.000 b
N T 120	0.000 d	0.000 d	0.000 b
N PB	5.432 c	17.980 c	0.500 b
	TSN	MSL (mm)	MSD (mm)
MHS T 50	1.455 a	52.660 a	3.780 a
MHS T 120	1.568 a	39.135 b	3.470 b
N T 50	0.000 b	0.000 c	0.000 c
N T 120	0.000 b	0.000 c	0.000 c
N PB	1.407 a	42.027 b	3.530 b

*Means followed by the same letter in the column do not differ by the Scott Knott test at 5% probability.

Concomitantly, it was observed that, at approximately 10 DAC, losses of number of remaining leaves began to occur for all treatments and, during the production process, they were more accentuated in seedlings produced in nurseries, mainly with the use of tubettes, and these losses were smaller in seedlings produced under MHS using 120-cm³ tubettes (Figure 1B, Table 1).

Shooting is a characteristic directly related to cutting growth and development. In this context, in the seedlings of treatments conducted in MHS (50- and 120-cm³ tubettes) and in a nursery with the use of polyethylene bags, there was a greater number of shoots (Table 1). However, they started only after 52 DAC. From this moment on, the seedlings produced by the mentioned treatments had a rapid growth in the number of shoots, with superiority for the seedlings of the treatments in a modified hydroponic system, especially in the case of seedlings produced in 120-cm³ tubettes. The delay for the beginning of shoot emission can be due to the lack of absorbent roots, responsible for absorbing water and nutrientes; this is the critical phase in seedling propagation by cuttings. The emission of shoots extended, in general, up to 112 DAC (Figure 1 C).

In the case of seedlings produced in nurseries, using tubettes (50 or 120 cm³), the emission of shoots was very small, which is consistent with the low survival and small number of remaining leaves (Figure 1A, B and C). In general, the plants produced in MHS using a 120-cm³ tubette showed a better behavior than the others studied (Table 1).

Growth characteristics are directly related to seedling development, and it is important to verify the adaptation to the cultivation system. It can be observed that the seedlings produced in 50- or 120-cm³ tubettes in a nursery environment did not survive and, therefore, did not show values different from zero for all the evaluated growth characteristics (Table 1 and Figure 1B).

Seedlings produced in MHS were always among those with the highest growth, in all evaluated characteristics, with no difference between those produced in the two tubette sizes in terms of NRL, height, NPB, and TSN, with differences that can reach 46.82% in NRL and 347% in NPB in relation to seedlings produced in polyethylene bags (Table 1).

Seedlings produced in MHS and in 50-cm³ tubettes were superior to those produced in 120-cm³ tubettes in terms of TLN, LRL, MSS and MSD, despite the lower survival (31.11% less), compared to seedlings in 120-cm³ tubettes (Table 1). In addition, greater heights and TSN were observed in seedlings conducted in MHS with 50- and 120-cm³ tubettes and in the nursery with the use of polyethylene bags, with no difference between these treatments. Although the total shoot number was greater in the seedlings produced in these treatments, the length and diameter of these shoots were greater in MHS with 50-cm³ tubettes, followed by MHS with 120-cm³ tubettes and nursery with polyethylene bags, which did not differ from each other (Table 1), making a difference that can reach 34.56% more in MSS and 8.93% in MSD.

Seedlings produced in MHS in 50-cm³ tubettes showed greater dry matter weight accumulation of leaves, stems, roots and total, indicating a balanced growth between shoot and root system in relation to the other treatments. Only seedlings produced in polyethylene bags in a nursery environment had a similar root dry matter weight (Table 2).

Thus, LDMW, SDMW and TDMW, per plant, were higher in seedlings produced in MHS with 50-cm³ tubettes, followed by MHS with 120-cm³ tubettes and nursery with polyethylene bags, not differing from each other, with differences reaching up to 97.88% for LDMW, 93.90% for SDMW and 93.04% for TDMW (Table 2).

In seedlings produced in MHS with 50-cm³ tubettes, there was greater total leaf area (TLA), followed by those grown in MHS with 120-cm³ tubettes and in a nursery with polyethylene bags, with a difference that can reach 330.37%. In addition, seedlings in MHS, regardless of the size of the container used, had higher values of leaf area ratio (LAR) and specific leaf area (SLA), when compared to those grown in nurseries (Table 2), with differences that can reach 177.84% and 130.25%, respectively.

SLM represents the amount of LDMW per TLA, indicating the relative proportion of assimilatory surface and leaf cell tissues, that is, higher SLM values observed in seedlings produced in nurseries using polyethylene bags may be related to greater leaf thickness (Table 2).

It is noteworthy that the system that provided the best leaf indices also presented the most developed root system (Tables 1 and 2), which reinforces the importance of the leaves in capturing light and transforming this light into chemical energy, which is essential for the development of the root system and plant growth.

Higher concentrations of chlorophyll a, b and total were observed in seedlings in MHS in both sizes of containers, with superiority of up to 37.41%, 82.24% and 47.56%, respectively (Table 3), in relation to nursery with polyethylene bags. Therefore, the accumulation of chlorophyll b can be related to better seedling development in a modified hydroponic system (Table 3).

Table 2: Leaf dry matter weight (LDMW), stem dry matter weight (SDMW), root dry matter weight (RDMW), total dry matter weight (TDMW), total leaf area (TLA), leaf area ratio (LAR), specific leaf area (SLA), leaf weight ratio (LWR) and specific leaf matter (SLM), of *Coffea canephora* seedlings, produced by cuttings in modified hydroponics (MHS) and nursery (N), in different containers (50-cm³ tubette – T 50; 120-cm³ tubette – T 120 and polyethylene bag - PB).

Treatments	LDMW (g)	SDMW (g)	RDMW (g)
MHS T 50	1.308 a	0.477 a	0.352 a
MHS T 120	0.665 b	0.246 b	0.196 b
N T 50	0.000 c	0.000 c	0.000 c
N T 120	0.000 c	0.000 c	0.000 c
N PB	0.661 b	0.264 b	0.451 a
	TDMW (g)	TLA (cm²)	LAR ($cm^2.g^{-1}$)
MHS T 50	2.137 a	4705337.6 a	2082.2 a
MHS T 120	1.107 b	2272781.6 b	2196.9 a
N T 50	0.000 c	0.000 c	0.000 c
N T 120	0.000 c	0.000 c	0.000 c
N PB	1.376 b	1093313.5 b	790.7 b
	SLA ($cm^2.g^{-1}$)	LWR ($g.g^{-1}$)	SLM ($mg.cm^{-2}$)
MHS T 50	3405.1 a	0.734 a	0.000318 b
MHS T 120	3655.7 a	0.732 a	0.000335 b
N T 50	0.000 c	0.000 b	0.000 c
N T 120	0.000 c	0.000 b	0.000 c
N PB	1587.7 b	0.718 a	0.000708 a

*Means followed by the same letter in the column do not differ by the Scott Knott test at 5% probability.

Physiologically, higher values of stomatal conductance and functionality were observed in seedlings produced in MHS in 50-cm³ tubettes, with superiority of the other treatments in at least 41.59% and 17.24%. Stomatal density and opening were higher in seedlings produced in MHS with 120-cm³ tubettes and in a nursery with polyethylene bags, followed by seedlings produced in a hydroponic system with 50-cm³ tubettes (Table 3), with differences of up to 23.62% and 108.36%, respectively.

Higher stomatal densities verified in plants in MHS with 120-cm³ tubettes and in a nursery with PB are probably related to the production system used, since the studied genotype was the same (Table 3).

For seedlings produced in MHS T 50, it was possible to observe lower values of stomatal density when compared to treatments MHS T 120 and PB (Figure 2). However, it was possible to verify superior results for stomatal functionality and conductance.

Table 3: Chlorophyll a, b and total, conductance (SC), density (DEN), functionality (FUN) and opening stomatal (SO), evaluated in *Coffea canephora* seedlings, produced by cuttings in modified hydroponics (MHS) and nursery (N), in different containers (50-cm³ tubette – T 50; 120-cm³ tubette – T 120 and polyethylene bag - PB).

Treatments	Chlorophyll a (ICF)	Chlorophyll b (ICF)	Total Chlorophyll (ICF)	SC (μmol m^{-2} s^{-1})	DEN (nº.mm^{-2})	FUN	SO (μm)
MHS T 50	395.947 a	152.580 a	548.528 a	313.600 a	355.405b	2.067 a	1.352 b
MHS T 120	401.895 a	156.053 a	557.947 a	221.477 b	427.115 a	1.677 b	2.370 a
N T 50	0.000 c	0.000 c	0.000 c	0.000 d	0.000 c	0.000 c	0.000 c
N T 120	0.000 c	0.000 c	0.000 c	0.000 d	0.000 c	0.000 c	0.000 c
N PB	292.474 b	85.632 b	378.105 b	56.667 c	439.382 a	1.763 b	2.817 a

*Means followed by the same letter in the column do not differ by the Scott Knott test at 5% probability.

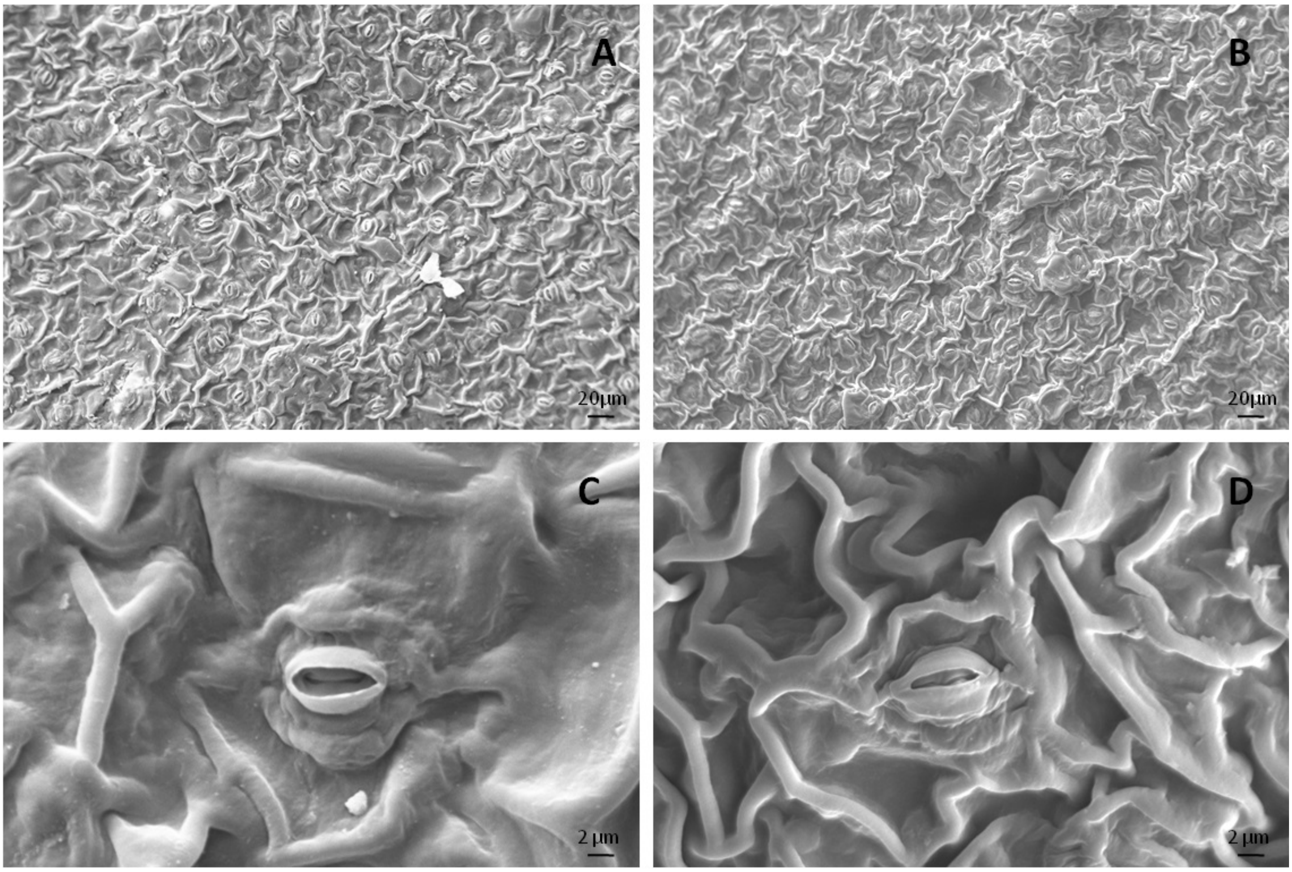

Figure 2: Electron micrographs of the leaf surface of *Coffea canephora* seedlings, showing the density and stomatal opening in seedlings produced in modified hydroponic systems: A and C - Seedlings produced using a 120-cm³ tubette. B and D - Seedlings produced using a 50-cm³ tubette.

In this research, it was possible to observe that the different production systems used, by providing different environmental conditions for cultivation, also led to different responses to the physiological performance of the seedlings (Table 3).

Seedlings with well-developed root systems are desirable, as this characteristic allows for greater exploitation of soil volume, and thus, greater capacity for absorption of water and nutrients. In this context, it was observed that the seedlings produced in MHS and N PB were efficient in the absorption of nutrients and water, which contributed to greater accumulation of LDMW, SDMW and TDMW (Table 2).

The chemical elements oxygen, fluorine, magnesium, aluminum, phosphorus, sulfur, potassium, calcium and silicon were detected in leaves and roots of *Coffea canephora* seedlings produced in MHS and in the nursery.

For all treatments, it was observed that most chemical elements are deposited homogeneously in plant tissues (leaf blade and roots), and that calcium and potassium were concentrated to a lesser extent in the vascularized region (Figures 3 and 4).

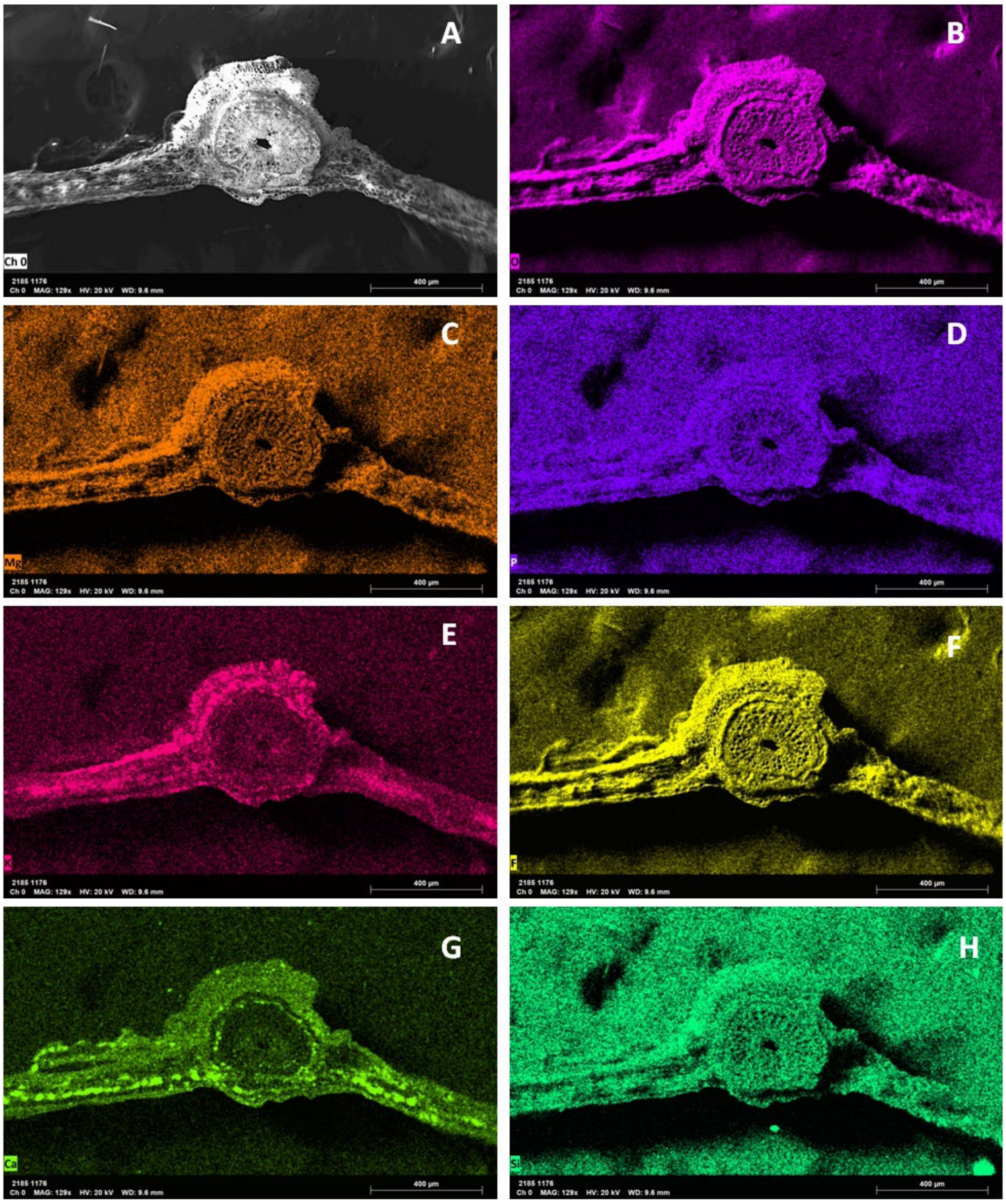

Figure 3: Scanning electron micrographs with x-ray microanalysis of the main chemical elements located in *Coffea canephora* leaves from cuttings. A: Cross section of the coffee blade, showing the mesophile and vascular bundle (analyzed region). Mapping indicating the location of chemical elements B: Oxygen, C: Magnesium, D: Phosphorus, E: Potassium, F: Fluorine, G: Calcium, H: Silicon.

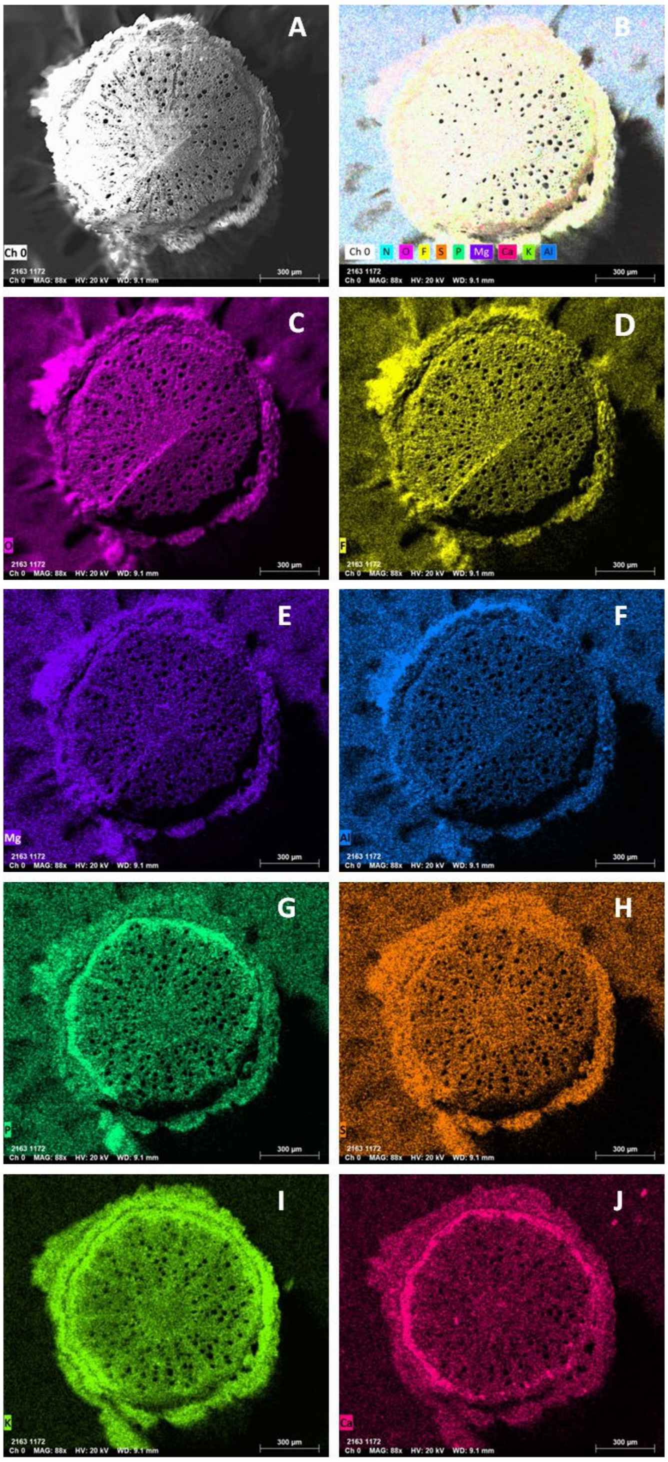

Figure 4: Scanning electron micrographs with x-ray microanalysis of the main chemical elements located in *Coffea canephora* roots from cuttings A: Cross section of coffee seedling roots (analyzed region). Mapping indicating the location of chemical elements B: Overlapping of the location of the chemical elements observed, C: Oxygen, D: Fluor, E: Magnesium, F: Aluminum, G: Phosphorus, H: Sulfur, I: Potassium, J: Calcium.

4 DISCUSSION

In this research, there are better indices related to the quality of *Coffea canephora* seedlings conducted in MHS. Within this system, it was possible to verify that there was greater seedling survival when produced in MHS+120 cm^3 (Figure 1, Table 1). However, the seedlings produced in MHS +50 cm^3 showed better results for several phytotechnical and physiological characteristics (Tables 1, 2 and 3), a fact that may be related to greater spacing and less competition between seedlings, due to lower survival in this treatment, which possibly contributed to better plant development.

The rooting of cuttings may be related to the presence of remaining leaves or at least part of them, due to the translocation of carbohydrates and auxins to the base of the cut, acting as a stimulant to rooting (Hartmann et al., 2011) and, consequently, resulting in greater survival.

The survival of seedlings in the systems may be related to water availability. In the nursery, sprinkler irrigation is easily drained until the next irrigation cycle, while in the MHS the tubes are in constant contact with the nutrient solution, which enables full-time water availability.

Seedlings produced in MHS were always among those with the highest growth, in all evaluated characteristics (Table 1). It is noteworthy that seedlings with higher values for plagiotropic branches and base diameter are desirable, as these characteristics have a high correlation with yield in future crops (Contarato et al., 2010).

In the seedling production process, it is important to evaluate the site of dry matter weight accumulation in its various parts, and not only the total dry matter weight; this is an important characteristic in the evaluation of plant development (Contarato et al., 2010).

Damato Neto et al. (2014) studied coffee genotypes in nutrient solution, and observed that biomass accumulation varies according to the cultivar used. Therefore, it is noteworthy that the variation observed in this study was possibly due to the cultivation systems.

The greater dry matter weight accumulation and higher values for growth characteristics of seedlings in MHS with 50-cm^3 tubettes may have occurred due to the lower seedling survival in this system, compared to those produced in 120-cm^3 tubettes in the same system, which provided a greater spacing of the seedlings in the trays and, thus, greater insolation and aeration, in addition to less competition for resources between the plants in this system (Table 1 and 2).

The exposure environment can cause changes in area, thickness, shape, nutrient concentration and gas exchange capacity in leaves (Sack; Holbrok, 2006). Thus, we observed that the different systems studied also promoted different responses. Giuriatto Júnior et al. (2020) evaluated the growth and quality of seedlings produced by *Coffea canephora* stem cuttings and also verified good seedling performance for the characteristics height, total dry matter weight, leaf area, root volume. However, they were produced in in another environmental condition using 280-cm³ tubettes using intermittent irrigation in a greenhouse.

In the modified hydroponic system higher concentrations of chlorophyll were observed (Table 3). Chlorophyll a and b contents are positively related to the activation of the photosynthetic process and, consequently, to plant development and adaptation to different environments. High photosynthetic rates can be observed in plants with high chlorophyll contents (Ramírez-Olvera et al., 2019). Chlorophyll b has the function of protecting the photosynthetic apparatus from photoinhibitory damage, through the dissipation of thermal energy and against oxygen to the PSII reaction center (Ramírez-Olvera et al., 2019).

According to Ribeiro et al. (2012), a high stomatal density with poorly functional stomata can cause excessive transpiration, making it difficult to adapt to growing conditions, as observed in this work, where the treatment with the best seedling production quality indices (MHS - 50 cm³) presented lower density and higher stomatal functionality (Table 3 and Figure 2B and 2D).

The modified hydroponic system provided full-time water availability via nutrient solution, which may have contributed to greater stomatal conductance in these treatments (Table 3). Under water-scarce conditions, coffee genotypes tend to reduce stomatal conductance to avoid excess transpiration (Dubberstein et al., 2020).

Factors such as temperature and water availability, with a single or combined occurrence, can alter the photosynthetic performance of coffee plants, and the increase in temperature changes the stomatal characteristics differently from drought (Dubberstein et al., 2020).

The root development of *Coffea canephora* can be influenced by characteristics such as propagation method and genotype (Partelli et al., 2014), environment (Silva et al., 2020) and, in this study, there was variation due to the production system and container.

Although the cultivation systems are different regarding the use of substrates, recipients, water and nutritional availability, there was no difference regarding the intensity and location of nutrients in the plants of the different treatments (Figures 3 and 4).

Plant development is influenced by their nutritional status, leading to effects on the supply of assimilates and growth substances (Taiz et al., 2017), and nutrient concentrations in coffee plants can vary according to the time of evaluation, plant tissue and climatic conditions such as rain and temperature (Oliosi et al., 2021).

5 CONCLUSIONS

The *Coffea canephora* seedlings production by cuttings in a modified hydroponic system is promising and shows high phytotechnical and physiological quality.

In nurseries, the use of polyethylene bags provides better seedling quality and survival than those produced in tubettes.

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7 AUTHORS' CONTRIBUTIONS

AEL, RJG and NNJC participated in the idea conception, NNJC development of the modified hydroponics technique, AEL, EMC and SHBC performed the experiment and wrote the manuscript, RJG and MAFC, supervised the experiment and co-work the manuscript, AMC and EA reviewed and approved the final version of the work, AEL conducted all statistical analyses.

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