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EFFECT OF THE SEED WEIGHT ON THE GROWTH OF YOUNG AVOCADO ROOTSTOCK SEEDLINGS

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ABSTRACT

The cultivation of avocado cv. Hass (*Persea americana* Miller) in Colombia has grown in recent years. Among the country's challenges is to increase the orchards' productivity by guaranteeing grafts plants the best agronomic, genetic, and phytosanitary parameters. This work aims to evaluate for 90 days (nursery phase) the growth and development of avocado rootstocks originated from seeds with different weight ranges. A completely randomized experimental design was carried out, with treatments consisting in four Creole avocado seed weights (40-60 g, 60-80 g, 80-100 g, and over 100 g). In general, seeds greater than 80 g had the best germination percentage (over 70 %), a greater plant height, and a greater stem diameter in each of the evaluated periods. The seeds greater than 100 g presented the emergence of multiple stems at 30 days after transplanting; this fact was related to the size and reserves of the cotyledons. The highest accumulated dry matter in stems, leaves, and total plant (without cotyledons) were present in treatments with seeds above 80 g. These plants showed higher germination, significant more accumulation of biomass and greater vigor, which could shorten the nursery time while guaranteeing the quality of the material influenced by improved growth and seedling survival.
Additional keywords: Dickson quality index, *Persea americana*, vigor

RESUMEN

Efecto del peso de la semilla en el crecimiento de plántulas de portainjertos de aguacate

El cultivo de aguacate cv. Hass (*Persea americana* Miller) en Colombia ha crecido en los últimos años, y entre los retos que tiene el país, está incrementar la productividad de los huertos mediante adecuada propagación del material, con portainjertos que cumplan con los parámetros de calidad agronómica, genética y fitosanitaria. El objetivo de este estudio fue evaluar durante 90 días (fase de vivero) el crecimiento y desarrollo de patrones de aguacate originados a partir de semillas con diferentes rangos de peso. Se realizó un diseño experimental completamente al azar, con tratamientos que consistieron en cuatro pesos diferentes de semillas de aguacate criollo (40-60 g, 60-80 g, 80-100 g y más de 100 g). En general, las semillas mayores de 80 g tuvieron el porcentaje de germinación más alto (mayor a 70 %), mayor altura de planta y mayor diámetro del tallo en cada uno de los periodos evaluados. Las semillas mayores de 100 g presentaron emergencia de tallos múltiples, a los 30 días después del trasplante, hecho se relacionó con la cantidad de reservas en la semilla. La mayor materia seca acumulada en tallos, hojas y total en planta (sin cotiledones), se presentó en los tratamientos con semillas con más de 80 g. Estas plantas, al presentar mayor porcentaje de germinación, vigor y acumulación de biomasa, podrían acortar los tiempos en vivero y garantizar la calidad del material, influenciado por el crecimiento y supervivencia de las plántulas.
Palabras clave adicionales: Índice Dickson, *Persea americana*, vigor

INTRODUCTION

The cultivation of avocado cv. Hass (*Persea americana* Miller) in Colombia has had accelerated growth, so between 2015 and 2019, the planted area increased (MADR, 2019), and the country ranks second in planted area worldwide, registering 63,534 hectares. In terms of production, it holds fourth place, achieving 7.5 % of the total produced worldwide with 535,021 Mg behind Mexico (32 %), Dominican Republic (9.2 %), and Peru (7.5 %) (FAO, 2020).

Among the challenges, Colombia has to consolidate in the international market. They are improving the orchards´ productivity and quality, and increasing the commercial fruit calibers.

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However, the country belongs to the tropical region, and it presents substantial variations at the altitude, geographical, climatic, and edaphic levels (Sánchez, 2013). Therefore, planting material is key to making any orchard successful, and it is necessary to certify the suitable agronomic, genetic, and phytosanitary quality in grafted plants (ICA, 2012).

A suitable rootstock must be compatible with the scion to be grafted; this means that there is close contact between the cambial zones to guarantee the expression of the desired characters in the scion, such as diseases resistance, stress conditions, local environments and improve performance and quality indices (Estay et al., 2016; Warschefsky et al., 2016). In this sense, Lestari et al. (2016) have been working on it in Indonesia, and evaluated some cultivars for parental plants that guaranteed the quality of the fruits, high-fat content, and continuous yield throughout the year.

In India, they consider that, due to cross-pollination, there is significant variability in the plants produced from seeds, which means that the orchards are not uniform and that the fruit's quality is not ideal (Tripathi and Karunakaranl, 2019). The rootstocks can be obtained from cultivars of the Guatemalan, Mexican or Antillean races, each with particular characteristics. In Chile, seeds of cultivars of the Mexican race are used (Castro et al., 2003). In Mexico, seeds are predominantly used from native cultivars, and in Brazil, nursery workers also opt for the use of seeds from non-grafted plants to obtain rustic rootstocks (Alberti et al., 2018).

The achievement of seed in different areas without meeting the minimum quality standards has generated a quantity of planting material that in the field begins to present problems mainly at the root level. Fittingly, a high genetic variability leads to having heterogeneous cultures with different reactions to edaphoclimatic and sanitary conditions (Ben-Ya'acov and Michelson, 1995). Consequently, the rootstock's seed must be from adult and productive trees, which have had at least two crops, well-formed, and their fruits are quality and healthy (Bernal et al., 2014).

For this reason, research is currently leading to the production of clonal trees that belong to selected genotypes to provide greater tolerance against root rot caused by *Phytophthora cinnamomic*, that finally meet quality and productivity standards (Alberti et al., 2018). Cloning is a slow process, and for this reason, while something more advanced is available, we continue working conventionally with seeds of Creole material that, in some cases, only the origin is known. Therefore, it must be guaranteed that all seeds to be sown meet minimum size, health conditions and are free from pests at the nursery level.

The largest discards of seed and material in the nursery have to do with not meeting the standards, not germinating, emitting more than one main stem, or generating multiple roots; many of these characteristics are related to the size and reserves present in the seed (Córdula et al., 2014). The seed quality influences the seedling vigor, growth, and survival of nursery plants after transplanting and is greatly influenced by cultivation techniques and environmental conditions, which assessing seedling vigor at the juvenile stage serves as an index for survival and growth of field plants (Kuan et al., 2019). Therefore, the present work hypothesizes that the size of the avocado seed affects the growth of the seedlings that will be used as rootstocks to produce planting material, so the study aimed to evaluate the growth and development of avocado originated from seeds with different weight ranges.

MATERIALS AND METHODS

Location. The study was carried out in the Cartama nursery, located in the department of Caldas, municipality of Supía (5°26'39" N; 75°38'56" W, 1185 meters above sea level) with average temperature between 22 and 24 °C. Annual average rainfall of 1,612 mm, with maximum and minimum relative humidity of 94 and 30 %, respectively.

Experimental design. A completely randomized experimental design was used, with four treatments and three repetitions. The treatments consisted of four weight ranges of Creole avocado seeds (40-60 g, 60-80 g, 80-100 g, and over 100 g), and each experimental unit consisted of 20 seeds. The seeds were extracted from fruits of Creole avocado trees (Guatemalan race) located in the municipality of Norcasia (Caldas). The seed was extracted from the fresh and ripe fruits three days after harvest of the tree. According to farmers' quality references, the trees were chosen and supported by the best expressions agronomic (yield, alternation, tree size and vigor, time to production, tolerance to abiotic stress, resistance to biotic stress, quality, and postharvest of fruit).

Figure 1 illustrates the seed weights distribution in each determined range, where a good selection of individuals is observed to categorize the four treatments evaluated.

The seed extracted from the fruit was disinfected, separated by weight range, and sown in seedbed; at 18 days, the transplant was carried out into plastic black bags, with dimensions of 50 cm high by 15 cm wide with perforations. The substrate was a mixture of 70 % soil, 20 % sand, and 10 % coffee beans and disinfected with 50 g of basamid (Dazomet 98 %). Based on substrate condition, avocado chemical fertilization was conducted by using the following nutrients per plant: N (1.31 mg), P_2O_5 (3.65 mg), K_2O (1.29 mg), MgO (0.039 mg), CaO (0.265 mg), S (0.520 mg), B (2.244 µg), Fe (0.426 µg), Mn (0.713 µg), Zn (0.316 µg), Cu (3.476 µg), and Mo (0.084 µg), applied through continuous fertigation after planting.

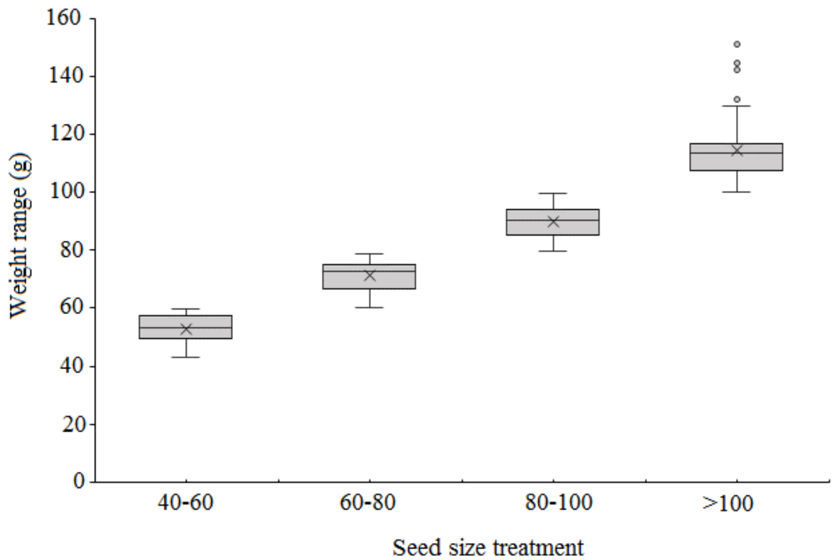

Figure 1. Box and whisker plot showing distribution of the seed weights in the determined ranges (40-60 g, 60-80 g, 80-100 g y >100 g)

Variables evaluated. For dry biomass variable, starting 15 days after transplanting (DAT), three plants were taken by treatment and repetition for three months. In each plant it was determined the dry matter of cotyledons (CDM), root (RDM), stem (SDM), leaf (LDM), and shoot dry matter (shoot included both stem and leaf). The measurements of growth variables were carried out in the same number of plants from 30 DAT for leaves number (LN), plant height (PH), stem diameter at 10 cm (SD), and shoot height (SH).

The Dickson quality index (DQI) was determined according to Binotto et al. (2010). This is an indicator that integrates morphological parameters and is often used during seedling selection. A high DQI value indicates a more desirable phenotype and better seedling vigor, indicating robustness and balance in the distribution of biomass in the seedling (Scalon et al., 2014). The index is a function of total dry matter (TDM), shoot height (SH), stem base diameter (SBD), shoot dry matter (SDM) and root dry matter (RDM), and is given by the expression:

$$\mathrm{DQI} = \frac{\mathrm{TDM}}{\frac{\mathrm{SH\ (cm)}}{\mathrm{SBD\ (mm)}} + \frac{\mathrm{SDM\ (g)}}{\mathrm{RDM\ (g)}}}$$

Growth analysis. Relative growth rate (RGR), net assimilation rate (NAR), and leaf foliar relation (LFR) were determined in 45, 60, 75 and 90 days after sowing, according to Hunt (2003), and Di Benedetto and Tognetti (2016). The leaf area (LA) was estimated using a portable leaf area meter Li-

Cor (Li-3000).

Statistical analysis. One-way analysis of variance (ANOVA) was performed after validation of the assumptions of normality and homoscedasticity (Shapiro-Wilk and Bartlett tests). For mean comparisons, LSD (least significant difference) test was performed with a significance level of $P \leq 0.05$, using the R Project Agricolae package.

RESULTS AND DISCUSSION

The beginning of germination occurs after 15 days of the sowing in the seedbed and its stabilization after 30 days. A direct relationship was observed between seed size and germination percentage, being 75 % for seeds greater than 100 g, 70 % for weights between 80 and 100 g, 68 % between 60 and 80 g, and 55 % for the lowest weights (40-60 g).

Similar results have been observed in avocado. Ndoro (2018) concluded that mass propagation of Hass avocado seedlings could be achieved using medium (3.5-4.5 cm) to large seeds (>4.5cm) due to quicker and the highest percentage germination. Large-sized seeds produced bigger girth, which significantly contributed to quicker graft take. In other similar study, Adjei et al. (2011) concluded that avocado seed emergence and germination are determined mainly by seed size, and medium (3.1-4.0 cm) to large (<4.0 cm) seed length were necessary for enhanced avocado seed germination.

The seedling emergence was observed 30 days after planting in plastic bags, where the first stems emerged. These times agree with that reported for the Callinson variety (Antillean race, group A), where seedling emergence and appearance began in the same way 30 days after sowing (Paixão et al., 2016). In that study, they found no differences in seedlings' emergence between the seed size and avocado cultivar, with percentages that varied between 84 and 92 %. However, according to Córdula et al. (2014), the success in germination and establishment of seedlings is associated with the size and quantity of seed reservations, which should be related to a greater nutritional reserve in bigger seeds. Large starch reserves accumulate in the seed during avocado fruit development, forming a pool of carbohydrates reserves sequentially broken down to sucrose used for initial embryo and seedling growth (Tefay et al., 2012).

At 90 days after sowing (DAS), plants from seeds heavier than 80 g presented greater LN, PH, and SD than the rest of the treatments, but in terms of LA, the treatments did not differ from each other (Table 1). For seeds over 80 g plants have heights and diameters greater than 43 cm and 8.5 cm, respectively, which is considered to have reached the ideal size for grafting. Seedlings from seeds greater than 80 g showed an increase of stem diameter by 16 and 32 % compared to the seedlings from seeds between the ranges 60 and 80 g and 40 and 60 g, respectively. Regarding height, results similar to those of diameter were observed; plants originating from larger seeds (over 80 g) presented higher heights of the order of 32 and 52 % compared to those from seeds of lower weights (below 80 g) (Table 1). Similar results were obtained by Adjei et al. (2011), who found a significant variation of 16 % in seedling girth eight weeks after germination due to differences in seed size. Medium and large-sized seeds produced seedlings with greater girth (0.7 cm) than small seeds.

Similarly, regarding canopy size, larger-size seeds produce a bigger canopy, significantly different from those of small size. In the study of Ndoro (2018), the largest stem girth was noted in seedlings from the large-sized seeds (0.8 cm); small, medium, and large seed sizes showed an increment in height and stem diameter over the period. The largest stem girth was noted in seedlings from the large (0,8 cm) and medium (0,6 cm) sized seeds, as well as the height of plants propagated from the large-sized seeds, was the highest 45 days after emergence.

Gálvez et al. (2016) indicated that homogeneous seedlings must reach at least 4,5 mm in diameter and 20 cm in length at the grafting moment. Nevertheless, Garbanzo and Coto (2017) and Maradiaga (2017) said that grafting in avocado should be carried out in rootstock with a diameter of approximately one centimeter and a height between 40 and 50 cm. Thus, the use of avocado varieties with seeds of greater weight would have a higher seedling growth rate than varieties with smaller seeds. This relation would not always be fulfilled given the influence of the genotype, such as demonstrated by Gálvez et al. (2016), who did not find an effect of the seed fresh weight on the growth of the seedling from seeds of the Esther variety of avocado taken from trees in a commercial orchard, with trees of the Hass variety as pollen donors. However, in the Cartama nursery, the selected homogeneous seedlings must have a stem that exceeds 5 mm in diameter and 30 cm in length at the time of grafting. Large seeds can bring benefits, starting from a faster development that shortens times in the nursery and a contribution to the good development of the tree in the field. This can be attributed to a higher amount of carbohydrates, oils, storage proteins, and other nutrients present in the large seed than in medium and small-sized seeds, factors related to increased vigor (Whiley and Anderson, 2002; Ndoro, 2018).

The key for a good compatibility rootstock-scion is to have a similar diameter in both tissues. Tripathi and Karunakaranl (2019), working with cleft grafts, showed the key to success was an appropriate alignment of vascular bundles that ensure a rapid rootstocks-scion union. Additionally, rootstocks with larger diameters allow better use of avocado buds that show development in larger diameter in many cases concerning that of the rootstocks.

Table 1. Growth variables of seedlings generated from different weight ranges of avocado seeds. Leaf number (LN), leaf area (LA), plant height (PH), and stem diameter (SD)

Treatment	Growth variables			
	LN	LA (cm^2)	PH (cm)	SD (mm)
		30 DAT		
40-60	9.18 bc	-	9.07 c	4.45 b
60-80	8.16 c	-	14.00 b	4.68 b
80-100	10.89 ab	-	18.54 a	5.41 a
>100	11.20 a	-	15.11 b	5.61 a
		45 DAT		
40-60	9.29 c	80.85 c	16.72 c	4.85 c
60-80	11.72 b	161.26 bc	21.51 b	5.59 ab
80-100	14.85 a	222.08ab	24.84 a	5.86 a
>100	14.19 a	312.22 a	27.14 a	5.14 bc
		60 DAT		
40-60	11.05 c	324.68 b	21.19 c	5.70 b
60-80	13.93 b	438.29 b	25.93 b	6.25 b
80-100	16.00 a	874.24 a	32.38 a	7.60 a
>100	16.65 a	938.97 a	32.15 a	7.98 a
		75 DAT		
40-60	12.00 d	696.45 b	24.61 c	6.70 b
60-80	14.57 c	1207.97 a	29.21 b	6.97 b
80-100	16.77 b	1286.61 a	37.37 a	8.39 a
>100	19.19 a	1291.97 a	38.08 a	8.53 a
		90 DAT		
40-60	14.80 b	-	28.79 b	6.63 c
60-80	16.20 b	-	33.14 b	7.51 b
80-100	20.56 a	-	43.00 a	8.51 a
>100	19.89 a	-	45.08 a	8.88 a

DAT (days after transplanting). (-): missing data
Means with different letters in each column and DAT differ according to LSD test ($P \leq 0.05$)

On the other hand, about the emergence of multiple stems after 30 DAT, the highest number of stems were observed in seedlings precedent of seed over 100 g, with an average of three stems which can be assigned by a greater nutritive reserve in biggest seeds, which stimulates the production of multi-stem rods (Paixão et al., 2016). The above mentioned is important to increase the propagules number and at the same time to enable the production of a higher number of seedlings per seed unit. In this sense, Souza et al. (2020) consider that it is possible to produce two or more seedlings or rootstocks with a single avocado seed after dividing each cotyledon into two parts. However, this may slightly delay the development of the seedlings.

At 45 DAT, all the evaluated weight ranges presented at least one plant with several stems; on average, 2.33 stems (over 100 g), 2.57 stems (80-100 g), 2.2 stems (60-80g), and 2.14 stems (40-60 g) were observed. Those stems were eliminated, and the main one was kept, which presented greater development.

The dry matter accumulated in the different tissues of the seedlings showed significant differences ($P \leq 0.05$) according to the weight ranges in the different evaluated periods. For example, the seedlings originating from seeds with more than 80 g always presented a higher accumulation of biomass (Table 2).

The highest dry matter accumulation in stems, leaves, and whole plants without including the cotyledons (TWCDM) was presented in treatments with seeds above 80 g, which exceeded the stem biomass up to 80 % after 90 DAT; 30 % of the leaves and 40 % of the TWCDM. According to Paixão et al. (2016), the obtained result should be associated with greater nutritional reserves in bigger seeds in avocado. Regarding the dry matter of the root, it is highlighted that, although there were differences up to 75 DAT, in the last evaluation carried out at 90 days, the root biomass did not vary between the different ranges of weights of seeds evaluated (Table 2). These results are complemented with those obtained for the root length variable at 90 DAT, where this variable did not differ significantly ($P = 0.767$) for each evaluated treatment, with values of 31.53 ± 2.967 g (40 to 60); 34.63 ± 3.339 g (60 to 80), 33.23 ± 1.906 g (80 to 100) and 35.37 ± 2.458 g (over 100).

Regarding the dry matter of the seed, in the same way, significant differences ($P \leq 0.05$) were observed according to the seed weight ranges in the different evaluated periods (Table 2), which is associated with the initial seed weight, which determined the ranges of seeds that were assessed. However, at 90 DAT, seeds over 80 g had consumed about 57 % of their dry matter or nutritional reserve compared to 15 DAT; while treatments below 80 g presented a reduction in the cotyledons dry matter of 64 % (60 to 80) and 29 % (40 to 60) respectively (Table 2).

In relation with the DQI, the highest values were consistently observed in seedlings originating from seeds weighing more than 80 g, compared to seeds weighing less than 80 g. Thus, the general trend observed for all tested plants is that larger seedlings had better DQI values. According to Kuan et al. (2019), the poor performance of smaller seedlings may be due to their relatively small root growth potential, leading to insufficient water uptake. However, at 90 DAT in our study, the root dry matter did not vary between seed weight ranges (Table 2).

According to Kuan et al. (2019), the plant quality influences the seedling vigor, growth, and survival of nursery plants after transplanting and is greatly influenced by cultivation techniques and environmental conditions, which assessing seedling vigor at the juvenile stage serves as an index for survival and growth of field plants. According to Wightman (1999), high vigorous seedlings exhibit strong growth, dominant stems, large root zones, balanced shoot/root ratio, tolerance to moderate drought, and high irradiation. The resulting index of the relation between shoot height and stem diameter expresses the balance in growth, also known as the sturdiness quotient, which is considered one of the most accurate indexes (Andrade et al., 2013).

Growth is the response to the interaction of genotype and environmental conditions; it describes changes in shape and size, which stop once the plants reach the phenological stage of maturity. Guatemalan race is adaptable geographically and climatically to tropical highlands and cold resistance. In Colombia, the trees of this race adapt to altitudes between 1000 and 2000 m. The fruits are thick and commonly rough/ woody/ stiff peel, small to big seeds tight in the cavity, large fruit, long ripening time (15 months) (Lestari et al., 2016; Bernal and Díaz, 2020). Guatemalan cultivars have the most useful horticultural genes. They dominate the germplasm of the world's 'subtropical' avocado cultivars that lead the world trade, and better types are recognized for desirable fruit quality. Their hybrids with Indian types dominate the world's tropical and semi-tropical industries, still based mainly on seedling trees in developing countries (Chanderbali et al., 2013; Schaffer et al., 2013).

The quantification has been based on adjusting classical and functional mathematical expressions to simple measurements such as the change in leaf area, height, diameter, and weight accumulation, among others. These have made it possible to indirectly characterize the plant physiological apparatus's efficiency to produce the morphological changes recorded in interaction with the environment (Paine et al., 2012; Gonçalves et al., 2013). Regarding the growth analysis, relative growth rate (RGR), net assimilation rate (NAR), and leaf area relation (LAR) did not vary significantly (*P*>0.05) among the ranges of weight in the different evaluated periods of 45, 60, 75 and 90 DAT (Figure 2).

Table 2. Dry matter accumulation (g) of seedlings generated from different weight ranges of avocado seeds. Root (RDM), stem (SDM), leaf (LDM), cotyledon (CDM), total without the cotyledons (TWCDM), and total dry matter (TDM). Dickson Quality Index (DQI)

Treatment	Dry matter (g)						DQI
	RDM	SDM	LDM	CDM	TWCDM	TDM	
			15 DAT*				
40-60	0.13 b	0.10 b	-**	14.60 b	0.23 b	14.84 b	-
60-80	0.28 ab	0.16 ab	-	22.77 b	0.44 ab	23.21 b	-
80-100	0.40 a	0.13 ab	-	29.36 b	0.53 a	29.89 b	-
>100	0.33 a	0.21 a	-	47.48 a	0.54 a	48.02 a	-
			30 DAT				
40-60	0.41 b	0.13 b	-	17.41 b	0.57 b	17.98 b	-
60-80	0.63 b	0.18 b	0.18 a	22.07 b	0.98 b	23.05 b	0.28 b
80-100	0.65 b	0.25 ab	0.24 a	24.17 ab	1.13 ab	25.31 b	0.27 b
>100	1.04 a	0.51 a	0.16 a	36.39 a	1.70 a	38.09 a	0.51 a
			45 DAT				
40-60	1.09 b	0.49 c	0.68 b	10.25 b	2.62 b	12.51 b	0.50 c
60-80	1.17 b	0.64 bc	1.02 b	15.13 b	2.82 b	17.96 b	0.54 c
80-100	2.11 a	0.88 b	1.26 b	18.80 ab	5.20 a	24.0 ab	0.95 a
>100	2.30 a	1.16 a	2.02 a	31.50 a	4.52 a	36.02 a	0.70 b
			60 DAT				
40-60	1.20 b	0.60 b	1.64 b	10.74 b	3.44 b	14.18 b	0.62 c
60-80	1.73 b	1.03 b	1.93 b	14.88 b	4.69 b	22.93 b	0.80 c
80-100	2.89 a	1.91 a	4.09 a	18.25 b	8.89 a	23.77 b	1.40 b
>100	3.51 a	2.25 a	4.72 a	32.59 a	10.49 a	43.08 a	1.74 a
			75 DAT				
40-60	2.13 b	2.20 a	3.90 b	11.36 b	8.23 b	19.59 b	1.26 c
60-80	3.26 a	2.04 a	6.64 a	11.72 b	11.94 ab	23.66 b	1.74 b
80-100	3.65 a	3.03 a	6.86 a	19.25 a	13.75 a	33.00 a	1.91 a
>100	3.79 a	3.24 a	7.07 a	19.80 a	13.90 a	33.71 a	1.95 a
			90 DAT				
40-60	4.10 a	2.64 b	6.00 b	10.37 b	12.74 b	23.10 b	1.97 c
60-80	3.77 a	2.70 b	6.46 b	10.61 b	12.92 b	23.53 b	1.89 c
80-100	5.98 a	4.59 a	8.09 a	12.50 b	18.65 a	31.16 ab	2.60 a
>100	4.86 a	4.36 a	8.09 a	20.50 a	17.31 a	37.81 a	2.27 b

*DAT (days after transplanting). **(-): missing data
Means with different letters in each column and DAT differ according to LSD test ($P \leq 0.05$)

This result suggests that relative avocado growth does not depend on the dry matter content or seed reserve, which may mean that the growth of the shoot is proportional to the reserves of the seed, with the same growth rate (Tefay et al., 2012), or reserves are proportional to the total growth but not to the growth speed. The plumule starts the growth of the simple primary leaves, concomitantly with the expansion of the first eophylls, which is the beginning of the development of the second pair of leaves (de Morais et al., 2010). The net assimilation of CO_2 increases approximately 42 days after budbreak and then stabilizes, indicating that avocado leaves were considered a sink of photoassimilates until about 40 days after sprouting (Mandemaker, 2008).

It might indicate that the C_6 metabolism dominates sugars in the seedling and the primary leaf. In contrast, the fifth fully expanded leaf is already predominantly C_7 sugars postulated to act as storage and transport in avocado. In this sense, the first stages of avocado development focus on accumulating metabolic carbohydrates such as C_6 sugars (glucose and fructose) necessary for initial growth, which are quickly consumed. While, in the advanced stages of development, the C_7 carbohydrates existing have an important function in avocado growth and development, including carbohydrate transport, carbohydrate reserves, and osmoprotectant.

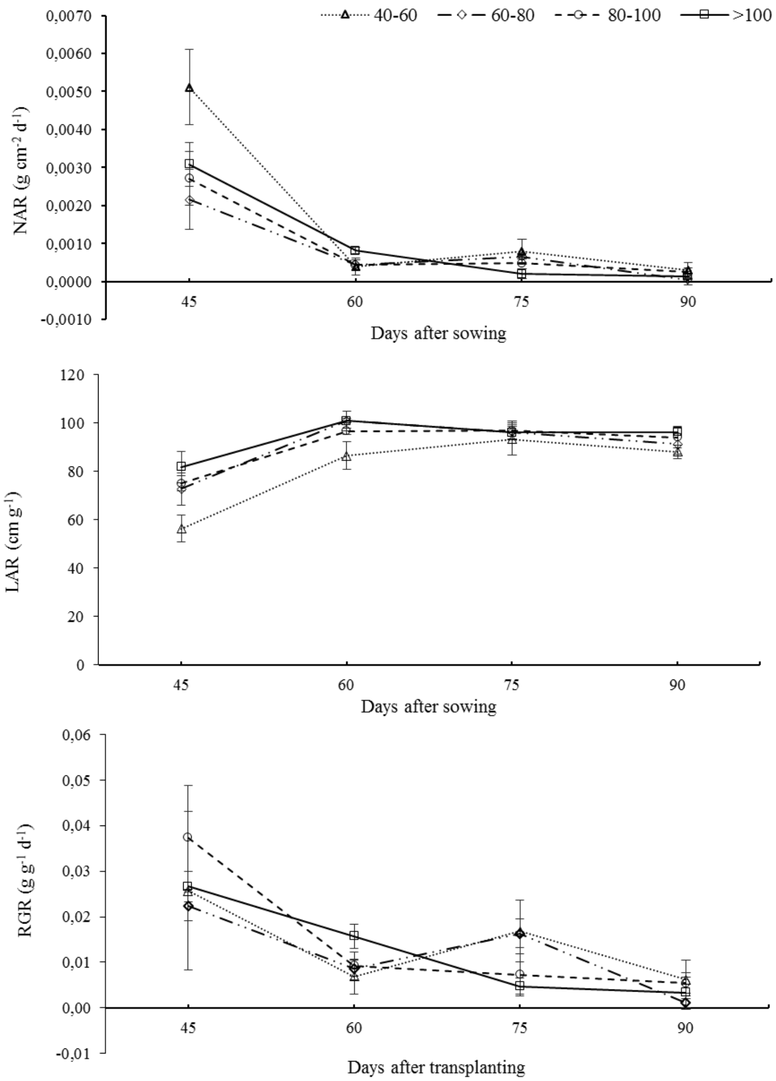

Figure 2. Net assimilation rate (NAR), Leaf area relation (LAR), and Relative growth rate (RGR) of seedlings generated from different weight ranges of avocado seeds

CONCLUSIONS

Plants originating from seeds with more than 80 g are ideal for use in the nursery, which presented a higher germination percentage, greater accumulation of biomass, and greater vigor, that could shorten the nursery time, thus guaranteeing the quality of the material. Using this kind of seeds, it can be reduced the percentage of discard in the nursery.

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LITERATURE CITED

1. Adjei, P.Y., B.K. Banful and I.A. Idun. 2011. Seed size and seed cut-length effects on germination behavior and seedling growth of avocado (*Persea americana* Merr.). International Journal of Agricultural Research 6(3): 299-305.
2. Alberti, M.F., B.D. Brogio, S.R. Silva, T. Cantuarias-Avilés and C. Fassio. 2018. Avances en la propagación del aguacate. Revista Brasileira de Fruticultura. 40(6): e-782.
3. Andrade, S.J., R.S. Alexandre, E.R. Schmildt, F.L. Partelli, M.A.G. Ferrão and A.L. Mauri. 2013. Comparison between grafting and cutting as vegetative propagation methods for conilon coffee plants. Acta Scientiarum 35(4): 461-469.
4. Ben-Ya'acov, A. and E. Michelson. 1995. Avocado rootstocks. *In*: J. Janick (ed.) Horticultural Reviews 17: 429. John Wiley and Sons, Inc. New York, NY. pp. 381-429.
5. Bernal, E.J.A. and D.C.A. Díaz. 2020. Generalidades del cultivo. *In*: Bernal. J.A.E. (ed.). Actualización tecnológica y buenas prácticas agrícolas (BPA) en el cultivo de aguacate. Agrosavia, Mosquera. pp. 77-330. https://n9.cl/n1a4y (retrieved March 18, 2021).
6. Bernal, J., C. Díaz, C. Osorio, A. Tamayo, W. Osorio, O. Cordoba, et al. 2014. Manejo del cultivo. Manual técnico actualizaciones tecnológica y buenas prácticas agrícola (BPA) en el aguacate. Corporación Colombiana de Investigación Agropecuaria – AGROSAVIA. Bogotá, 470 p. https://n9.cl/0l998 (retrieved March 18, 2021).
7. Binotto, A.F., A.D.C. Lúcio and S.J. Lopes. 2010. Correlations between growth variables and the Dickson quality index in forest seedlings. Cerne 16(4): 457-464.
8. Castro, M., R. Cautin, C. Fassio and N. Darrouy. 2003. Introduction, Selection and Propagation Program for Avocado Rootstocks and Cultivars (Abstracts. A–35). *In*: World Avocado Congress V. Granada-Málaga, Spain. pp. 120-121.
9. Chanderbali, A.S., D.E. Soltis, P.S. Soltis and B.N. Wolstenholme. 2013. Taxonomy and Botany. *In*: Schaffer, B., B.N. Wolstenholme and A.W. Whiley (eds.) The avocado: botany, production and uses. CAB International, London. 32 p.
10. Córdula, E., M.P. Morim and M. Alves. 2014. Morfologia de frutos e sementes de Fabaceae ocorrentes em uma área prioritária para a conservação da Caatinga em Pernambuco, Brasil. Rodriguésia 65(2): 505-516.
11. de Morais O.I.V., R.S. Costa, F.V. Môro, A.B.G. Martins and R.R.S. Da Silva. 2010. Caracterização morfológica do fruto, da semente e desenvolvimento pós-seminal do abacateiro. Comunicata Scientiae 1(1): 69-69.
12. Di Benedetto, A. and J. Tognetti. 2016. Técnicas de análisis de crecimiento de plantas: su aplicación a cultivos intensivos. RIA. Revista de Investigaciones Agropecuarias 42(3): 258-282.
13. Estay, C., R. Cautín, A. Neaman and M. Castro. 2016. Clonal propagation of the avocado: effects of the rooting step on graft union formation and development. International Journal of Agriculture and Natural Resources 43(2): 233-241.
14. FAO (Food and Agriculture Organization of the United Nations). 2020. FAOSTAT Online Database. http://www.faostat.fao.org/. Retrieved February 20, 2021.
15. Gálvez-Cendegui, L., P. Peñaloza, E. Oyanedel and M. Castro. 2016. Caracterización del tamaño de semilla nodriza de aguacate Esther y el desarrollo de sus plántulas. Revista Fitotecnia Mexicana 39(1): 79-85.
16. Garbanzo, S.M. and A.A. Coto. 2017. Manual para el establecimiento y manejo de un vivero de aguacate (*Persea americana*. Mill) (No. F01/10905). Ministerio de Agricultura y Ganadería, San José (Costa Rica). http://www.mag.go.cr/bibliotecavirtual/F01-10905.pdf.
17. Gonçalves, J.F.D.C., E.G.D.F. Melo, M.J. Ferreira, C.E.M.D. Silva and I.B. Gomes. 2013. Crescimento, partição de biomassa e fotossíntese em plantas jovens de *Genipa*

spruceana submetidas ao alagamento. Cerne 19(2): 193-200.

18. Hunt, R. 2003. Growth analysis, individual plants. *In*: Thomas B., D.J. Murphy and D. Murray (eds.). Encyclopedia of Applied Plant Science. Academic Press, London. pp. 588-596.

19. ICA (Instituto Colombiano Agropecuario). 2012. Manejo fitosanitario del cultivo del aguacate Hass (*Persea americana* Mill) - Medidas para la temporada invernal. Bogotá, Colombia. 75 p. https://n9.cl/kaya6 (retrieved April 10, 2021).

20. Kuan-Hung, L.I.N., W.U. Chun-Wei and Y.S. Chang. 2019. Applying Dickson quality index, chlorophyll fluorescence, and leaf area index for assessing plant quality of *Pentas lanceolata*. Notulae Botanicae Horti Agrobotanici Cluj-Napoca 47(1): 169-176.

21. Lestari, R., L.A. Sukamto, P. Aprilianti, S. Wahyuni and W.U. Putri. 2016. Selection of Avocado Plants Based on Fruit Characters, Fat content, and Continual Harvest along the year in West Java-Indonesia. International Journal on Advanced Science, Engineering and Information Technology 6(1): 77-83.

22. Mandemaker, A.J. 2008. Photosynthesis of avocado. New Zealand Avocado Growers' Association Annual Research Report 7:1-9.

23. Maradiaga, R. 2017. Manual técnico para el manejo de viveros certificados de aguacate (No. IICA F01). Programa Regional de Investigación e Innovación por Cadenas de Valor Agrícola Secretaría de Agricultura y Ganadería (Honduras). Dirección de Ciencia y Tecnología Agropecuaria. Instituto Interamericano de Cooperación para la Agricultura.

24. MADR (Ministerio de Agricultura y Desarrollo Rural). 2019. Cadena de Aguacate. Indicadores e Instrumentos. Bogotá, Colombia. 34 p. https://n9.cl/anod (retrieved September 23, 2021).

25. Ndoro, L.L. 2018. Effect of Seed Size on Germination and Seedling Performance on Grafted Avocado. African Journal of Education, Science and Technology 4(4): 95-100.

26. Paine, C.T., T.R. Marthews, D.R. Vogt, D. Purves, M. Rees, A. Hector and L.A. Turnbull. 2012. How to fit nonlinear plant growth models and calculate growth rates: an update for ecologists. Methods in Ecology and Evolution 3(2): 245-256.

27. Paixão, M.V.S., J.C. Lopes, E.R. Schmildt, R.S. Alexandre and C.M. Meneghelli. 2016. Avocado seedlings multiple stems production. Revista Brasileira de Fruticultura 38(2): e-221.

28. Sánchez, J.A.E. 2013. Los Suelos de Colombia. *In:* Burbano, H.O. and F.M. Silva (eds.). Ciencia del suelo principios básicos. Offset Grá. Bogotá. 610 p.

29. Scalon, S.P., T.S. Jeromin, R.M. Mussury and D.M. Dresch. 2014. Photosynthetic metabolism and quality of *Eugenia pyriformis* Cambess. seedlings on substrate function and water levels. Anais da Academia Brasileira de Ciências 324: 103-113.

30. Schaffer, B., B.N. Wolstenholme and A.W. Whiley. 2013. Introduction. *In*: Schaffer, B., B.N. Wolstenholme and A.W. Whiley (eds.). The avocado: botany, production and use. CAB International, London, UK. 4 p.

31. Souza, J.A.C., G.C. Prates, J.T. Ferreira, G.D.M.D. Castro and L.C.C. Salomão. 2020. Avocado: Is it possible to produce two seedlings with one seed? Revista Ceres 67: 152-155.

32. Tefay, S. Z., I. Bertling, J.P. Bower and C. Lovatt. 2012. The quest for the function of 'Hass' avocado carbohydrates: clues from fruit and seed development as well as seed germination. Australian Journal of Botany 60(1): 79-86.

33. Tripathi, P.C. and G. Karunakaran. 2019. Standardization of time and method of propagation in avocado. Journal of Applied Horticulture 21(1): 67-69.

34. Warschefsky, E.J., L.L. Klein, M.H. Frank, D.H. Chitwood, J.P. Londo, E.J. von Wettberg and A.J. Miller. 2016. Rootstocks: diversity, domestication, and impacts on shoot phenotypes. Trends in Plant Science 21(5): 418-437.

35. Whiley, A. and G. Anderson. 2002. Study tour of South Africa, New Zealand, the UK and

the USA (also incorporating Chile). Horticulture Australia, Sydney, Australia. 56 p. https://n9.cl/5n84i (retrieved April 10, 2021).

36. Wightman, K.E. 1999. Good tree nursery practices: practical guidelines for community nurseries. International Centre for Research in Agroforestry (ICRAF), Nairobi, Kenya. 94 p. https://n9.cl/dyqn2 (retrieved April 10, 2021).