

Phenology and Growth of Forage Sugarcane Cultivars According to the Planting Cycle

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Abstract

Context: Plant phenology and growth exhibit quantitative relationships that help in understanding its biomass production capacity. Therefore, a detailed understanding of its general and specific characteristics is crucial for efficient exploitation.

Aim: To characterize the phenology and growth of forage sugarcane cultivars C97-366 and C99-374 according to the planting cycle.

Methods: Two experiments were planted during the spring (April) and cold (October) cycles in the areas of the Sugarcane Research Institute (INICA) in Camagüey, Cuba, under rainfed conditions. A randomized complete block design with two treatments (cultivars) and three replicates was used. Evaluations were conducted monthly, between 181 and 368 days. The variables evaluated were fresh and dry plant weight, dry matter, and green and dry biomass production.

Results: The forage cultivars did not show similar growth dynamics across planting cycles. These variations were significantly influenced by the seasonal behavior of climatic variables, particularly precipitation and temperature. Both cultivars achieved average green biomass values (80-135 t ha⁻¹) and dry biomass (30-38 t ha⁻¹) that exceed the average reported in Cuba under rainfed conditions. The cultivar C99-374 achieved the highest productivity and stability in each cycle.

Conclusions: The forage cultivars can be used year-round to feed ruminants due to their high genetic potential for biomass production.

Keywords: C97-366, C99-374, cold cycle, spring cycle, biomass production.

Introduction

Sugarcane is one of the tropical crops that produces the most biomass per unit area and with the highest efficiency in capturing solar energy compared to any other plant, with up to 1.7 grams of biomass per Mega Joule of solar radiation received (Aragón et al., 2009). Additionally, it has the advantage of being perennial, adaptable to different soil types, resistant

to pests, not causing erosion, and requiring few fossil-derived inputs (Bezerra et al., 2017; dos Reis et al., 2019). This crop is an alternative source as a forage supplement due to its low cost for producing a ton of dry matter and maintaining its nutritional value during periods of pasture scarcity (Martín, 2005; Vidal, 2018).

Currently, it is important to consider the adverse effects generated by climate change, among which the reduction and instability of the rainfall regime, coupled with the intensification of extreme meteorological phenomena (such as droughts and hurricanes), and the increase in atmospheric CO₂ concentration stand out (Rodríguez, 2012). For these reasons, there is a need to use sugarcane in feeding ruminants, not only in the dry period but throughout the year, as long as the appropriate cultivar is selected and the proper management is practiced for this purpose.

In Cuba, to achieve proper sugarcane management that ensures meeting the needs of ruminants throughout the year and achieving productive levels equal to or higher than those obtained on small-scale agricultural producers' farms, it is necessary to establish a forage bank at different times of the year. In this system, the sugarcane cultivar plays the primary role, as not all genotypes are capable of maintaining their productivity under unfavorable climatic conditions, especially the rainfall regime.

Fernández (2022) demonstrated that the selection scheme of sugarcane used in Cuba can be utilized to obtain and recommend varieties for sugarcane production and obtain genotypes with potential for forage production. This author obtained very positive results in characterizing the agronomic and nutritional behavior of the C97-366 and C99-374 cultivars, chosen following forage criteria, in livestock areas of the province of Camagüey.

Considering that plant phenology and growth show quantitative relationships that allow understanding its biomass production capacity (Özalkan et al., 2010), it is fundamentally important to have a detailed understanding of its general and specific characteristics to make its exploitation efficient.

This paper aims to characterize the phenology and growth of the forage sugarcane cultivars C97-366 and C99-374 according to the planting cycle.

Materials and methods

The study was done in areas of the Sugarcane Research Institute (INICA) in Camagüey, located in the Municipality of Florida at coordinates 21° 31' North Latitude and 78° 04' West Longitude, at 57.08 meters above sea level, on grayish-brown soil, according to the classification of Hernández et al. (2015).

Two experiments were established, one planted in the spring cycle (April 2014) and the other in the winter (October 2014). The relative humidity throughout the spring study averaged 76.28%, with maximum, minimum, and average temperatures of 31.4, 21.4, and 25.5 °C, respectively. The total rainfall was

1,430.4 mm with 111 rainy days. In the winter cycle, relative humidity averaged 76.13%, with maximum, minimum, and average temperatures of 31.7, 22.2, and 25.7 °C, respectively. The total rainfall was 1 127.8 mm with 113 rainy days (Florida Agrometeorological Station, 2016).

Each experiment was planted using a randomized complete block design with two treatments (cultivars) and three replicates. Each experimental plot had five rows of 10 meters in length, spaced 1.50 meters apart, for a total area of 75 m². The three central rows of each plot were considered the useful area for sampling, discarding 0.5 meters at the beginning and end of each row. Fertilization was carried out according to the dosage recommended by the Fertilizers and Amendments Recommendation Service (SERFE) for this type of soil (INICA, 2014). Initial weed control was made in early post-emergence, followed by periodic manual control every 3-4 months. The experiment was conducted under rainfed conditions.

The forage cultivars evaluated in the study were C97-366 and C99-374 recommended by INICA (2019). The dynamics of fresh and dry plant weight, dry matter, and green and dry biomass production were evaluated monthly from 181 to 368 days after planting. Evaluations of the spring cycle began in October 2014 and ended in April 2015, coinciding with the dry season in Cuba. In the cold weather cycle, evaluations began in April 2015 and concluded in October of the same year (rainy season).

For determining fresh and dry weight, three representative plants (stems and tops) were cut per plot using a machete, performing the cut at ground level. Then they were immediately transported to the Plant Physiology Laboratory, where they were processed independently. Each plant was divided into two fractions, stem, and top, which were weighed (fresh weight) and transferred to the greenhouse area for drying, where temperatures exceed air temperature (> 7 - 20 °C). Later, they were taken to the laboratory for final drying, and were placed in an oven with forced air circulation at 70 °C until a constant weight (dry weight) was achieved. Dry matter was determined by the percentage ratio between the dry weight of the sample and the fresh weight. Green biomass production (t ha⁻¹) was determined by direct weighing of 1 m² of plant material per plot, which was extrapolated to a hectare. Dry biomass (t ha⁻¹) was calculated by multiplying the dry matter value (%) by the green biomass (t ha⁻¹) divided by 100.

The dynamics of variations in all the variables studied concerning plantation age by cycles are illustrated using (xy scatter) graphs.

Results and discussion

Fig. shows the dynamics of fresh plant weight by age according to the planting cycle of the forage sugarcane cultivars C97-366 and C99-374. No similar behavior between cultivars was observed concerning the dynamics of green biomass accumulation. A higher productivity of the C99-374 cultivar can also be seen in both planting cycles, showing a greater fresh plant weight.

The C97-366 cultivar in the winter conditions planting cycle was characterized by a very discreet increase in fresh plant weight from 181 to 244 days of age, at which point a sustained increase occurred until 342 days. From this period until 368 days, the plant increased its fresh weight by only 36.40 g. This behavior is closely related to the climatic conditions that prevailed during the study (Fig. 2). In the first three evaluations, the plant was recovering from stress caused by the low rainfall regime from November to March, during which it had to develop a series of morphological and physiological mechanisms to mitigate and adapt to the adverse conditions generated by this event. Once recovered under favorable conditions from April to June, it showed high efficiency in accumulating assimilates, a characteristic of C4 plants.

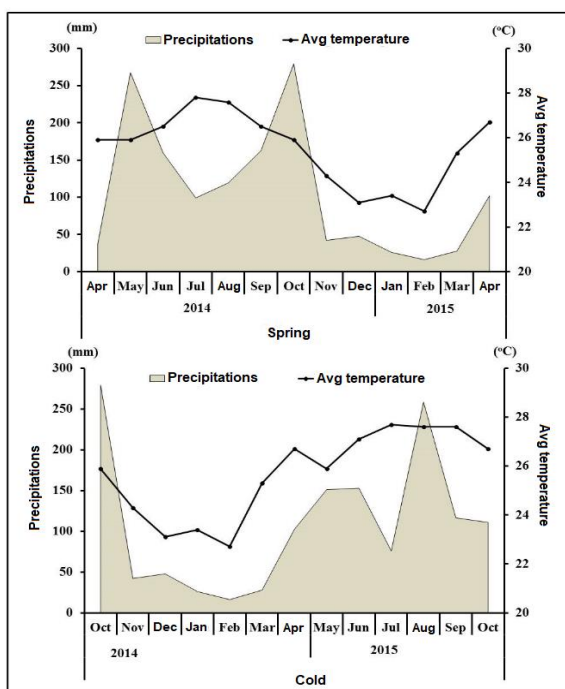


Fig. 1. Dynamics of Fresh Plant Weight by Age According to Planting Cycle of Forage Sugarcane Cultivars C97-366 (A) and C99-374 (B)

In the spring cycle, this genotype showed a tendency to increase fresh plant weight from 181 to 310 days, with the greatest increase occurring between the first and second evaluations. From 310 to 368 days, a decrease in fresh plant weight was observed. This

behavior throughout the cycle is also closely related to the prevailing climatic conditions during the study (Fig. 2)

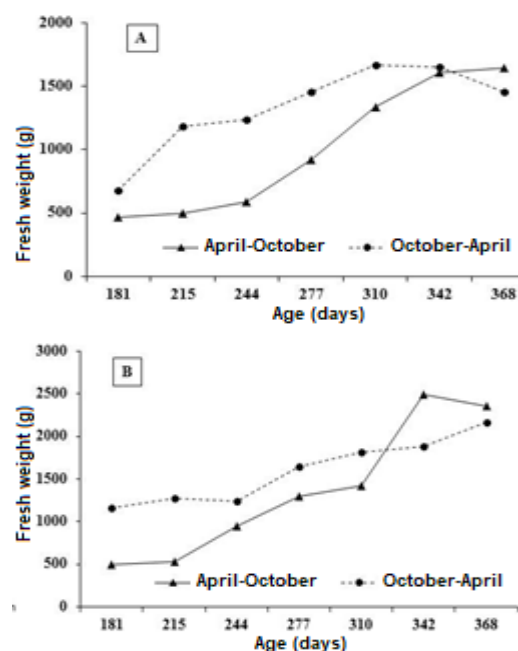


Fig. 2. Monthly Temperature and Precipitation Behavior by Planting Cycles

The plant developed under optimal conditions from sprouting to the beginning of the vegetative phase of maximum growth, with a large amount of well-distributed rainfall and high temperatures favoring its development. The positive effect of these variables was confirmed by the highest monthly increase in November, resulting from the highest rainfall recorded in October, as the rains have a cumulative effect on the sugarcane crop. This means a positive response in the plant was observed 10 to 15 days after the occurrence of the rain. This cultivar reached its peak fresh biomass production at 368 (1 645.65 g) and 310 (1 669.43 g) days in the cold and spring planting cycles, respectively.

The C99-374 cultivar in the cold cycle showed a slight increase in fresh plant weight during the first two evaluations. It then showed a progressive increase with age up to 342 days, reaching its maximum value (2 494.42 g). Afterwards, this genotype showed a decrease of 138.55 g in fresh weight. This behavior can be largely attributed to the edaphoclimatic conditions that prevailed during the study (Fig. 2), with arguments very similar to those commented on for the C97-366 cultivar, except for the decrease observed in the last evaluation, which is presumed to be closely related to the maturation phase of the crop. In this phase, the plant is characterized by decreasing biomass production and using energy in the process of translocation and accumulation of sucrose in the stem.

In the spring cycle, this cultivar showed a slight increase at 215 days, followed by a decrease in fresh weight in the next evaluation. Then, an increase of 922.81 g was observed from 244 to 368 days, accumulating a fresh weight of 2 159.31 g at the last evaluation date. This cultivar showed a very positive behavior, considering that it maintained very stable biomass accumulation despite the evaluations coinciding with the period of the least rainfall reported in the study (Fig. 2). Therefore, it can be affirmed that this forage sugarcane has a high genetic potential for biomass production and drought tolerance.

Lower values to those obtained in this study were published by Blanco et al. (2003) in a similar study evaluating four commercial sugarcane cultivars from six to 13 months of age. These authors found values that did not exceed 300 g per plant⁻¹, demonstrating the genetic potential of these two forage cultivars for biomass production, the main characteristic justifying the use of this crop as animal feed.

Fig. 3 shows the dynamics of dry matter (DM) of the plant by age according to the planting cycle of forage sugarcane cultivars C97-366 and C99-374. A similar behavior was observed between the cultivars in terms of DM accumulation by the plant in each planting cycle.

In the spring cycle, they showed a decrease that ended in a slight increase in the last two evaluations. In the cold cycle, this same behavior occurred inversely, meaning from 181 to 215 days of age, no increase in DM was observed, rather there was a decrease in the case of the C97-366 cultivar. Subsequently, both genotypes showed an increase until reaching their highest values in the last two evaluations.

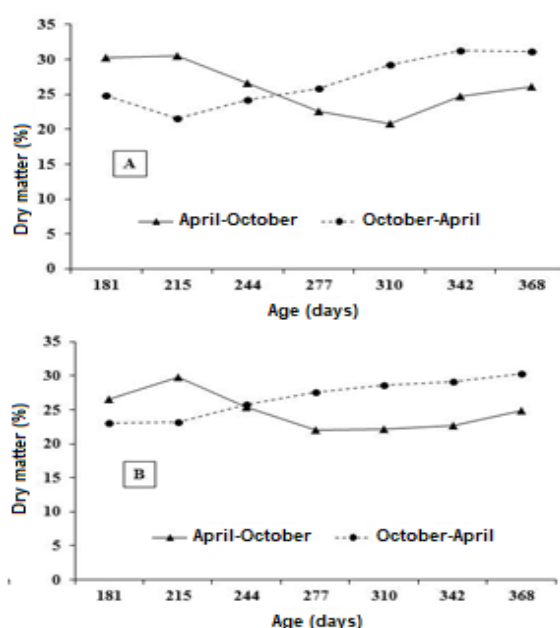


Fig. 3. Dynamics of dry Matter (DM) of the plant by age according to planting cycle of forage sugarcane cultivars C97-366 (A) and C99-374 (B)

This behavior clearly shows that despite the C97-366 cultivar having a higher DM content at some ages compared to the C99-374, the greatest variation in this indicator was attributed to the climatic variables that prevailed in each planting cycle in the study location (Fig. 2).

In the cold cycle, evaluations began at 181 days coinciding with April, so in previous months, except for October when planting took place, low rainfall conditions were present, promoting less plant development and consequently lower water content in its tissues due to water stress.

The opposite occurred in the spring cycle when evaluations began at a time when the plant was in good physiological condition, with high moisture content in its tissues due to the high and well-distributed rainfall recorded during the period before the start of evaluations.

These reasons justify the higher DM content in the cold cycle in the initial evaluations. However, in the last ages evaluated, this behavior by cycles reversed, meaning the highest DM values were reached in spring as evaluations coincided with the dry period of the year, where the plant was subjected to the adverse conditions of water stress. Accordingly, the DM content of the sugarcane plant is closely related to climatic conditions, where precipitation and temperature have a significant impact on this indicator's behavior.

Similar results were published by Valladares et al. (2009) in a study of three sugarcane cultivars planted in spring, with an increase in DM overtime. They highlighted that the period between eight and 16 months had the highest assimilation accumulation rate. This increase in DM could be closely related to the increase in the proportion of the plant cell wall with age, though other factors such as water availability, root system development, and the time of year could also influence it (Fernández & Pedraza, 2019).

In the cold and spring cycles, the C97-366 cultivar reached average DM values of 25.93% and 26.86%, respectively, for an overall average of 26.40% DM per plant. On the other hand, the C99-374 achieved average values of 24.79% and 26.80% in the cold and spring cycles, respectively, for an overall average of 25.80% DM. Both cultivars showed average values by cycles higher than those published by Heuzé et al. (2018) as a result of a bibliographic compilation on the chemical composition of sugarcane, reporting an average value of 23.2% DM for the whole sugarcane plant.

Fig. 4 shows the dynamics of dry weight of the plant by age according to the planting cycle of forage sugarcane cultivars C97-366 and C99-374. The behavior of both cultivars across the two evaluation cycles was very similar.

In both planting cycles, the cultivars showed a tendency to increase dry plant weight as the crop age increased, with the exception of the C97-366 which showed a decrease on the last evaluation date in the spring cycle. This behavior could have been influenced by the low rainfall regime that occurred from December to March (Fig. 2). Specifically, the C99-374 genotype surpassed the dry weight accumulation exhibited by the C97-366 cultivar in both planting cycles. These results demonstrate its high genetic potential for biomass production and drought tolerance, showing increases in dry weight even when climatic conditions were unfavorable for the crop's development (spring cycle).

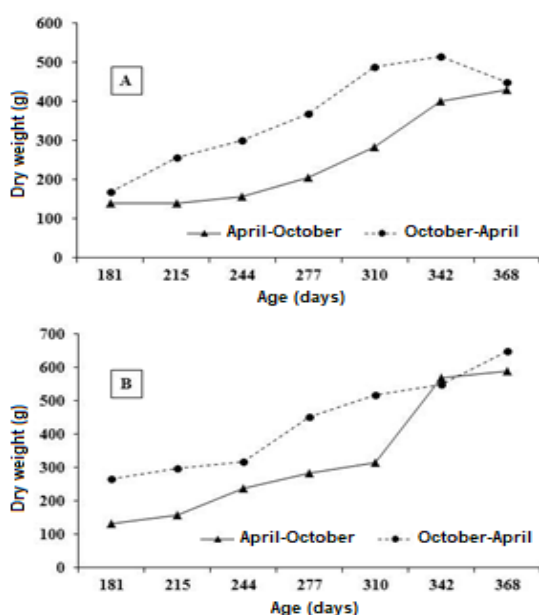


Fig. 4. Dynamics of dry plant weight by age according to planting cycle of forage sugarcane cultivars C97-366 (A) and C99-374 (B).

Both forage cultivars achieved dry weight values higher than those published by Blanco et al. (2003) in a study of four commercial sugarcane cultivars selected in Cuba for industrial use in sugar production.

Fig. 5 shows the dynamics of green biomass production by age according to planting cycle of forage sugarcane cultivars C97-366 and C99-374. There was a trend towards increased green biomass production with age, except in the C97-366 cultivar, which showed a decrease in the last evaluation of the spring cycle. This could have been caused by the climatic conditions prior to the evaluation period (Fig. 2), where low rainfall and lower temperatures were recorded, conditions that could also have affected the maturation process. During this

vegetative phase, the plant loses weight by mobilizing sucrose, releasing reducing sugars that are subsequently degraded for energy (ATP) production through required respiratory processes.

The C99-374 cultivar showed a very stable performance, with values above 100 t ha^{-1} of green biomass in the final evaluations of each cycle. These results were very favorable for the rainfed conditions under which this study was conducted and confirmed the potential of this genotype for forage use. The C97-366 cultivar maintained values ranging between 60 and 80 t ha^{-1} of green biomass from 215 to 368 days in the spring cycle. In the cold cycle, it exceeded 100 t ha^{-1} of green biomass in the last two evaluations.

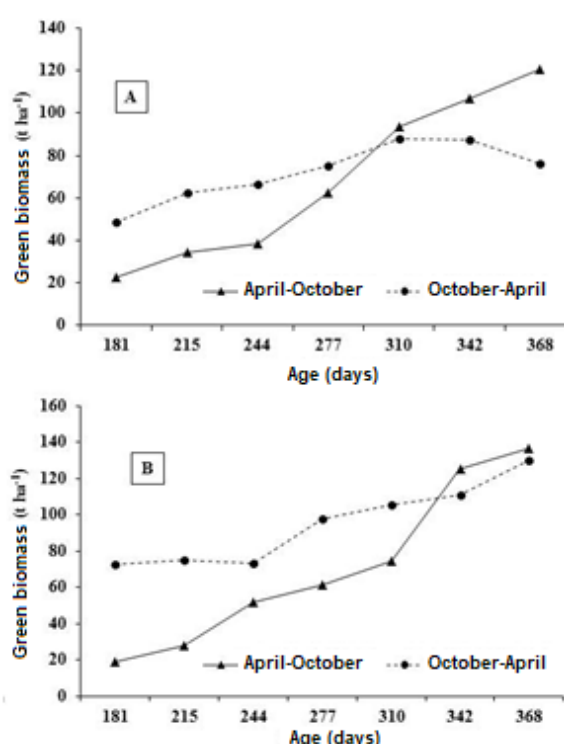


Fig. 5. Dynamics of green biomass production by age according to planting cycle of forage sugarcane cultivars C97-366 (A) and C99-374 (B).

The average green biomass values obtained in this study are higher than those published in Cuba by several authors, who have reported productions ranging from 59 to $114.2 \text{ t ha}^{-1} \text{ year}^{-1}$ of green biomass in sugarcane cultivars recommended for diversified use in animal feed under rainfed conditions (Franco, 1981; Molina et al., 1995; Milanés et al., 1997; Molina et al., 2000; Leyva, 2012).

Fernández-Gálvez et al. (2019) in 12 sugarcane cultivars recommended for bovine feeding, including the two forage cultivars, green biomass values at 14 months of age ranged between 69.37 and 167.54 t ha^{-1} .

1, with a general average in the study of 111.26 t ha⁻¹. These values were similar to the ones reported in this study.

These results back the high forage potential of forage sugarcane cultivars C97-366 and C99-374 for ruminant nutrition in Cuba.

Fig. 6 shows the dynamics of dry biomass production by age according to planting cycle of forage sugarcane cultivars C97-366 and C99-374.

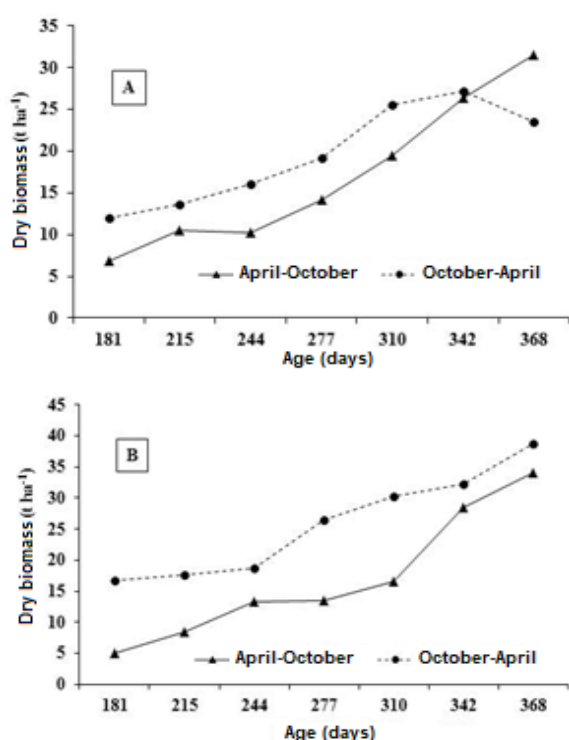


Fig. 6. Dynamics of dry biomass production by age according to planting cycle of forage sugarcane cultivars C97-366 (A) and C99-374 (B)

A very similar behavior to the dynamics of green biomass production was observed, with a sustained increase in both cycles as age increased, except for the C97-366 cultivar, which showed a decrease in the last evaluation of the spring cycle.

The C99-374 cultivar showed the highest productivity in the study in each of the evaluated cycles, reaching average dry biomass values of 34.04 and 38.71 t ha⁻¹ at 368 days of age in the cold and spring plantations, respectively. The C97-366 reached its highest dry biomass values at 342 days in spring (27.17 t ha⁻¹) and at 368 days in cold (31.53 t ha⁻¹).

In Cuba, Franco (1981); Molina et al. (1995 and 2000); Milanés et al. (1997) published dry biomass production values ranging from 20.40 to 33.21 t ha⁻¹ under rainfed conditions. Similar results to those obtained by the C97-366 cultivar in this study. The

C99-374 surpassed the values published by the previously mentioned authors.

In this century, sugarcane has been widely used in Brazil for animal feed. Values between 21.80 and 39.88 t ha⁻¹ year⁻¹ of dry biomass under rainfed conditions have been published by Andrade et al. (2003); Bonomo et al. (2009) and Caione et al. (2011). Similar values to those achieved in this study.

Freire et al. (2010) conducted an evaluation of 11 Brazilian sugarcane cultivars under optimal irrigation conditions. These authors reported dry biomass productions between 48 and 90 t ha⁻¹, higher than those obtained in this study, reaffirming the importance of water in sugarcane cultivation.

Conclusions

The forage sugarcane cultivars did not show similar growth dynamics by planting cycles. Variations were strongly influenced by the seasonal behavior of climatic variables, especially precipitation and temperature. The C99-374 cultivar stood out for achieving the highest productivity and in a stable manner in each cycle.

Author contribution statement

Yoslen Fernández Gálvez: Research planning, experiment setup, results analysis, article writing, final review.

Redimio Manuel Pedraza Olivera: Research planning, results analysis, article writing, final review.

Yoslen Fernández Caraballo (Junior): Results analysis, article writing, final review.

Isabel Cristina Torres Varela: Experiment setup and evaluation, results analysis, interpretation.

Joaquín Montalván Delgado: Results analysis, article writing, final review.

Josué García Febles: Results analysis, article writing, final review.

Conflict of interest statement

The authors declare no conflicts of interest.

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