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# Biomass yield and chemical composition of the cassava plant over two vegetative growth cycles

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**ABSTRACT.** The objective of this work was to study the biomass production and chemical composition of the different parts of the cassava plant during the first and second vegetative cycles, with the aim of providing data that can contribute to the understanding of the response of cassava cultivars to different harvest ages. The experimental design consisted of randomized blocks in split plot scheme. Plots were represented by cultivars IAC 90 and IAC 118-95 and subplots by crop age (2, 4, 6, 8, 10, 12, 14, 16, and 18 months after planting). Our results showed that the 'IAC 90' allocated a higher proportion of assimilates to the leaves, stem and planted cutting than the 'IAC 118-95', which was more efficient in allocating dry matter to the storage roots. Storage roots showed an increase of more than 50% in starch content 14 months after planting. The cultivar IAC 118-95 is distinguished by the higher harvest index, allowing earlier harvesting, with possible valorisation of the leaves as industrial raw material. Variables showed different degrees of inter-relationships amongst themselves. Total plant fresh matter and dry matter yields were positively correlated with growth parameters and root starch for both cultivars. Harvest time and cultivar are key factors that should be considered to increase profits in the cassava agro-industrial chain.

**Keywords:** crop age; cultivar; dry matter allocation; harvest index.

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## Introduction

Cassava crops have been gaining prominence in international and national agricultural scenarios owing to their adaptation to adverse environments. Bitter cassava, used in industry, are processed to obtain various products, such as starch and flour, and as a potential raw material in the international market to obtain biofuel (Zhu, 2015; Leonel et al., 2015; Orek, Gruissem, Ferguson, & Vanderschuren, 2020).

World cassava production increased by 72.6%, from 175.9 million tons in 2000 to 303.6 million tons in 2019, with a harvested area of 23.4 million hectares in 2019. Globally, Nigeria accounted for 26.2% of area under cassava cultivation with an accumulated growth of 118.6% from 2000 to 2019. Countries such as Uganda, the Democratic Republic of Congo, and Thailand also showed significant growth during this period at 213%, 150.1%, and 22.6%, respectively. South American cassava production accounts for 9.09% of the total world production, with Brazil being the largest producer (17.64 million tons) (FAO, 2020; Alves, Felipe, & Cardoso, 2022).

In the agricultural industrialisation of cassava in Brazil, the starch segment is considered the most organised, with approximately 80 industries in the country. In 2020, the national production of starch was 538.81 thousand tons, with the state of Paraná accounting for 66.6%, Mato Grosso do Sul 19.3%, São Paulo 9.2%, and Santa Catarina 3.2%; Bahia and Pernambuco accounted for remaining amount of production. The production of cassava flour in Brazil in 2018 was 948.66 thousand tons, with the northern states being the largest producers. The production of gum or tapioca was 36.6 thousand tons, with the states of Minas Gerais, Amazonas, Pará, and Bahia as the main producers of this product (Alves et al., 2022).

The cassava growth cycle from planting to harvest can vary depending on the cultivar and region, being shorter in areas with higher temperatures, and longer in colder or drier regions. Irrigation management can also lead to shorter cycles. During growth, the plant goes through five main physiological phases, four active states and one vegetative rest (El-Sharkawy, 2003; Silva, 2021; Vidigal Filho & Sagrilo, 2022).

Cassava cultivation using two vegetative cycles is a management technique practised mainly in Brazil for industrial cassava. In this cultivation system, plants undergo a period of physiological rest between the end of the first and beginning of the second vegetative cycle, a period that occurs at the coldest and driest time of the year. The second vegetative cycle of cassava begins with the regrowth of the stems, stimulated by the increase in temperature and the return of rain, and the plants undergo another period of intense vegetative growth (Otsubo & Lorenzi, 2004).

A major drawback of cultivating two-cycle crops is that producers only obtain revenue when they sell the product, which negatively affects the competitiveness of the crop against other crops, especially in the regions with satisfactory rainfall conditions (Duarte & Kanthack, 2017; Alves et al., 2022).

One of the main strategies that can be applied by farmers and industries is the diversification of cassava cultivars, thereby allowing better incomes and low industrial idleness owing to the supply of raw material throughout the year. Therefore, this study aimed to evaluate the effects of plant age on fresh and dry mass yields and the composition of cassava plant parts of the two cultivars during the first and second vegetative cycles.

## Material and methods

### Climatic characteristics and location of the experiment

The experimental trial was installed on 03 November 2017 in a producer's area, in the city of Lupércio, São Paulo state, Brazil (latitude 22°24'54" S, longitude 49°49'02" W, and altitude 661 m). The predominant climate of the study area is hot and temperate, with significant rainfall throughout the year, with an annual average of 1,295 mm. The climate is classified as Cfa, temperate, or humid, with an average annual temperature of 20°C. Daily rainfall and temperatures were measured during the experimental period (Data from the National Institute of Meteorology (INMET), Meteorological Station of São Carlos, São Paulo State, Brazil). (Figure 1).

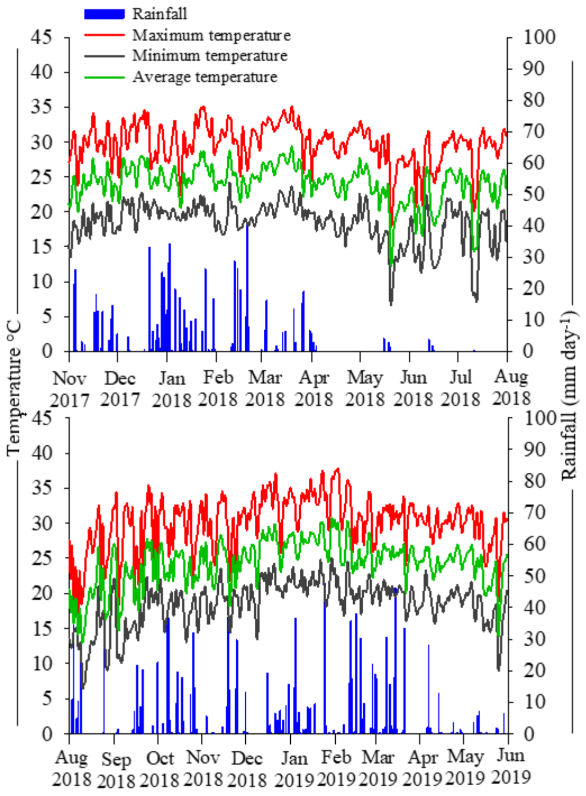

**Figure 1.** Daily rainfall (I), and maximum (-), average (-) and minimal (-) temperatures at the experimental area during the period of cassava growing in the field. (Lupércio, São Paulo State, Brazil).

### Cultivation practices

The soil in the experimental area was classified as an abrupt red-yellow argisol. Prior to the experiment, soil samples were collected in subplots at a 0–20 cm soil depth for chemical analysis. The following results were obtained: pH ($CaCl_2$) 5.4; Organic Matter,9 g dm$^{-3}$; $P_{resin}$, 32 mg dm$^{-3}$; H + Al, 19 mmol$_c$ dm$^{-3}$; K, 1.81 mmol$_c$

$dm^{-3}$; Ca, 25 $mmol_c\ dm^{-3}$; Mg, 14 $mmol_c\ dm^{-3}$; SB, 40 $mmol_c\ dm^{-3}$; ECEC, 59 $mmol_c\ dm^{-3}$; base saturation, 68%; S, 3 mg $dm^{-3}$; B, 0.45 mg $dm^{-3}$; Cu, 8 mg $dm^{-3}$; Fe, 19 mg $dm^{-3}$; Mn = 2 mg $dm^{-3}$; and Zn = 1.40 mg $dm^{-3}$. Prior to conducting the experiment, the area was also cultivated with cassava.

The experimental design used was randomised blocks in a split-plot scheme with four replicates. The plots were represented by two cassava cultivars (IAC 118-95 and IAC 90), and the subplots were represented by the crop age (2, 4, 6, 8, 10, 12, 14, 16, and 18 months after planting-MAP). Each experimental plot was 25 m wide and 50 m long, and each subplot was represented by six cassava plants, which were harvested in each evaluation period, and the adjacent plants that were not harvested in the following evaluations, that is, at all times, plants that had competitive plants (borders) were always harvested.

Soil was prepared by harrowing, subsoiling, ploughing, terracing, and levelling. In addition, organic fertiliser (chicken manure) was applied at 2.1 t $ha^{-1}$; soil correction was carried out using 1.7 t $ha^{-1}$ of dolomitic limestone. These procedures followed the cultural practices of the regional producers.

Mechanised planting occurred in November 2017. A planter (Bazuca 4, PlantiCenter, Marialva-PR, Brazil) with four rows and a New Holland 7630 110 hp tractor were used in this study. The parameters adopted were stem cuttings of 13-cm-long with 11 to 12 buds; 65 cm spacing between plants and 90 cm of rows; and fertilisation with 300 kg $ha^{-1}$ with the formula NPK 4-30-10 (12, 90, and 30 kg $ha^{-1}$ of N, $P_2O_5$, and $K_2O$, respectively). After planting, spraying was carried out to control weeds, and side dressing fertilisation was performed 90 days after planting using 124 kg $ha^{-1}$ KCl.

### Harvest and post-harvest analysis

At all harvest times, four plants were collected per sub-plot. After harvesting, in the experimental field, the plants were separated into leaves, stems, planted cuttings and roots. The number of leaves per plant, stem height, and stem diameter were analysed. Fresh samples were then weighed to measure the fresh matter content in the plant parts and the productivity of fresh roots per plant. The quantity of fresh matter, and the productivity of fresh roots per plant were multiplied by the plant population (17,094 plants $ha^{-1}$) to obtain fresh matter yield and root productivity per hectare.

Subsamples of each part of the plant were stored in boxes with ice-bags and transported to the laboratory where they were dried to a constant weight in an air circulation oven at 65°C for 96 hours to determine the dry matter content in the plant parts. The dry matter yield in the leaves, stems, planted cutting, roots, and total plant was calculated from the data of dry matter content in the parts of the plant, the accumulation of fresh matter, and the productivity of fresh roots.

The harvest index was calculated as the percentage of the ratio of the dry matter accumulation in the roots and that in the total plant.

Cassava plants harvested at different times were analysed following AOAC methods for moisture (934.06), protein (920.152), ash (923.03), lipid (923.05), fibre (920.86), total sugars (968.28), and starch (996.11) (Horwitz, 2005).

### Data analysis

Analysis of variance and the F test at a 5% probability level ($p < 0.05$) were used for the analysis of the experimental data. When there was significance in the F test, the means for the qualitative factors were compared using the t-test (DMS, $p < 0.05$). The effects of plant age were evaluated by regression analysis, and the magnitude of the significant regression coefficients at 5% probability was used as a criterion for choosing the model by the F test ($p < 0.05$). However, for the chemical composition of cassava plant parts, no regression equations were presented because no regression model fitted to adequately describe the data. Pearson´s correlation was applied to check the linear correlations between the parameters studied for each cultivar.

## Results and discussion

The morphological parameters of the cassava plants varied mainly with harvest time in the first cycle and with cultivar and harvest time in the second cycle (Figure 2). The effect of crop age on growth parameters is related to plant physiology and climatic conditions (El-Sharkawy, 2003). Cassava plant has a long cultivation cycle undergoing marked edaphoclimatic variations (Figure 1). In addition, interactions occur between the shoot and root system of the plants as they compete for light, water, nutrients, and space that can influence the growth of the different plant organs in different ways.

The number of leaves per plant followed quadratic models for the two vegetative growth cycles (Figure 2). During the first two months, the cassava plant mainly develops shoots (stems and leaves) and a fine root system. Cultivars do not differ for number of leaves in the first cycle, with a peak at 4 MAP and leaf fall at 8 MAP, when rainfall and temperature are lower (Figures 1 and 2). In the second cycle, there is an exponential increase in number of leaves for both cultivars, with higher values for 'IAC 90' only at 12 MAP. Hydric and temperature stresses tend to increase the formation of new leaves in cassava plants with higher photosynthetic rates (El-Sharkawy, 2003; Gabriel et al., 2014).

Stem diameter increased at the beginning of the two growth cycles (greater flow of photoassimilates between shoots and roots), with stabilisation in the phases of completion of shoot growth and beginning of the phase of thickening of the roots, indicating remobilisation of photoassimilates for the new growth cycle (El-Sharkawy, 2003) (Figure 2).

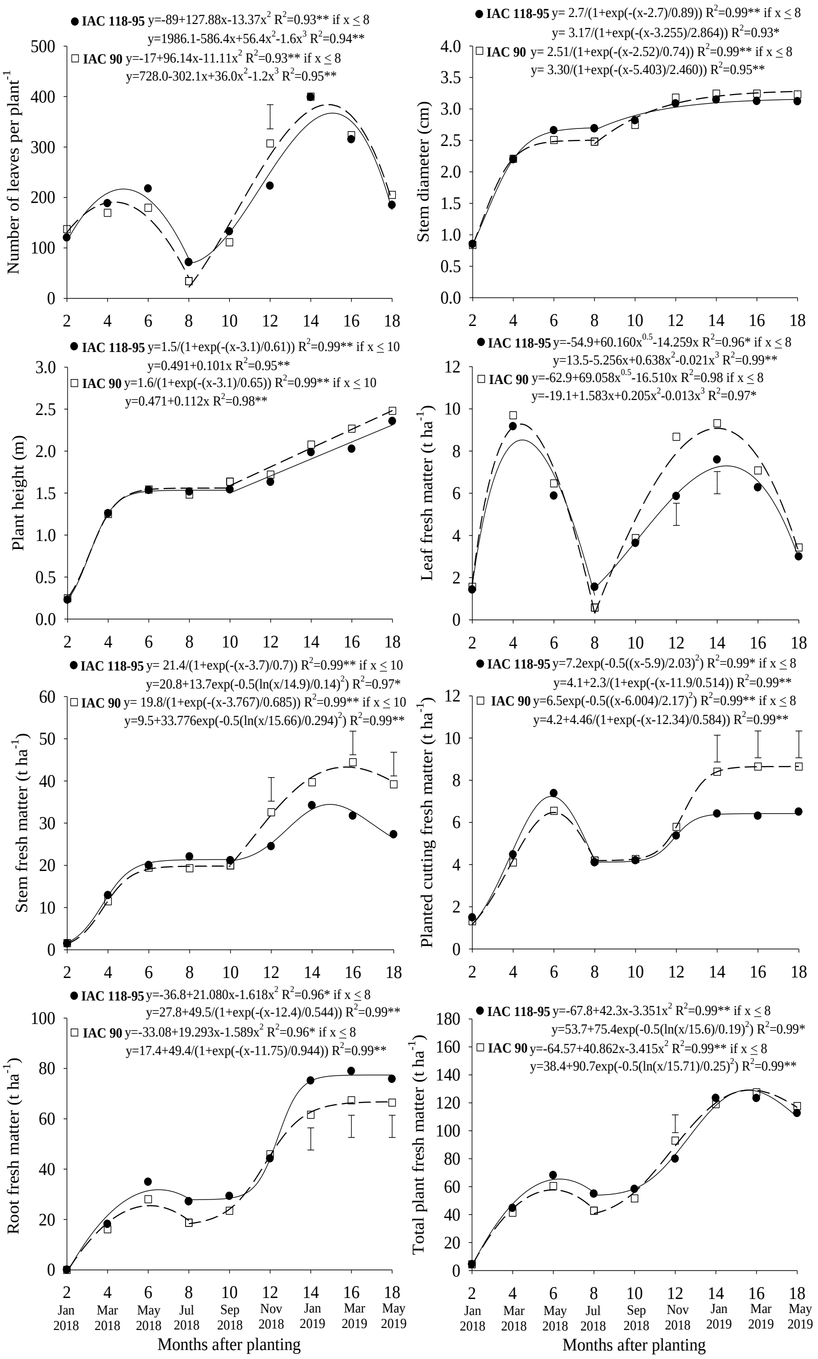

**Figure 2.** Variations in morphological parameters and fresh matter yield of the cassava plant during the first and second cycles of vegetative growth. (Lupércio, São Paulo State, Brazil). * and ** are, respectively, significant at 5 and 1% probability by the F test. The presence of a vertical bar (DMS value) at the time indicates a significant difference between the cultivars according to the t test (DMS, $p < 0.05$).

Cassava plants had the same height growth model, characterised by an initial exponential growth up to 4 MAP in the first cycle, followed by a stabilisation period, and a new exponential growth in the second cycle up to 18 MAP (Figure 2). The plants reached 1.5 m in the first vegetative cycle at 6 MAP and remained stable until the dormancy period, indicating the effect of climatic stress (Figures 1 and 2). At the end of second cycle, plants reached their maximum height at 18 MAP. The sensitivity of the shoots of the plant to reduction in water availability can be perceived as an adaptation to drought rather than a physiological restriction. The values obtained for plant height were in agreement with those reported by other authors for different cassava cultivars (Otsubo & Lorenzi, 2004; Sagrilo et al., 2006; Siloko et al., 2021).

Cultivar IAC 90 showed greater accumulation of fresh matter in the shoot (leaves, stem, and planted cutting) in the second vegetative cycle, which did not occur in the roots (Figure 2). The cultivar IAC 118-95 accumulated higher levels of fresh matter from the 14 MAP. Silva, Miglioranza, and Kanthack (2011) analysed the fresh matter production of the two studied cultivars (330 DAP) and observed fresh matter yield of the shoot as 19.6 and 13.9 t ha$^{-1}$ for ‘IAC 90’ and ‘IAC 118-95’, respectively.

Plant growth was impaired due to the occurrence of very low rainfall and lower temperatures after 4 MAP. A strong correlation exists between agricultural productivity and weather variables, particularly temperature and rainfall, because the biological growth process of plants is directly dependent on weather conditions (Siloko et al., 2021).

Dry matter yields in parts of cassava plants and total plants showed that leaf dry matter yield had a quadratic performance with higher values occurring in periods of high temperatures for both cultivars (Figures 1 and 3). Significant differences were observed between the cultivars only at 12 and 14 MAP, when the ‘IAC 90’ had a higher leaf dry matter yield. Shoot production is directly associated with the production capacity of the planting material, and consequently, with the ease of propagation of a particular cultivar.

Cultivar IAC 118-95 had a greater accumulation of dry matter in the roots, in addition to a higher harvest index (0.72 at 18 MAP), differing from the ‘IAC 90’ which accumulated higher levels of dry matter in the leaves, stems, and planted cutting (Figure 3).

At the beginning of senescence in the first vegetative cycle, genotype differentiation for the production of root dry matter occurred (Figure 3). In this phase, the accumulation of dry matter in the roots of the cultivar ‘IAC118-95’ was 53% higher than that of ‘IAC 90’. In the second growth cycle, the cultivars differed in terms of root dry matter yield from 14 MAP. The higher harvest index of ‘IAC 118-95’ suggests a greater efficiency of plants in allocating carbohydrates produced by the photosynthetic process in the tuberous roots, i.e. it indicates a better balance between shoot and tuberous root production of the cultivar.

The total biomass produced results from the total photosynthetic assimilation throughout the growing season less all respiratory losses. Thus, the accumulation of biomass throughout the plant depends on the efficiency with which the cultivar intercepts light and converts it into biomass throughout the vegetative cycle (Enesi et al., 2022).

The dry matter accumulation of the ‘IAC 90’ cassava plant and the harvest index obtained were similar to those reported by Sagrilo et al. (2006) (10.2 to 25.6 t ha$^{-1}$ for root production, with a harvest index ranging from 49.2 to 59.6%).

Results showed that ‘IAC 118-95’ had an early harvest characteristic for the edaphoclimatic conditions of the study. It obtained a harvest index above 60% from 14 MAP, a percentage considered adequate for cassava (Vidigal-Filho et al., 2000).

The correlation analysis showed that the variables showed different degrees of inter-relationships amongst themselves. Total plant fresh matter (TPFM) and dry matter (TPDM) yields were positively correlated with growth parameters for both cultivars, as well as were positively correlated with fresh and dry matter of plant parts (Table 1).

Leaf number is directly related to solar interception and photosynthesis, thus contributing to fresh matter yields in stem, planted cutting and root. Rao et al. (2017) evaluating several cassava genotypes reported significant correlation between fresh root yield and growth and yield characteristics (plant height, stem girth, canopy diameter, number of leaves per plant, leaf area, number of roots per plant, root diameter, root length, and root weight).

The harvest index of IAC 118-95 was positively correlated with all morphological parameters, which did not occur for IAC 90. For both cultivars, the harvest index was positively correlated with the roots dry matter yield, but for IAC 118-5 the correlation was stronger.

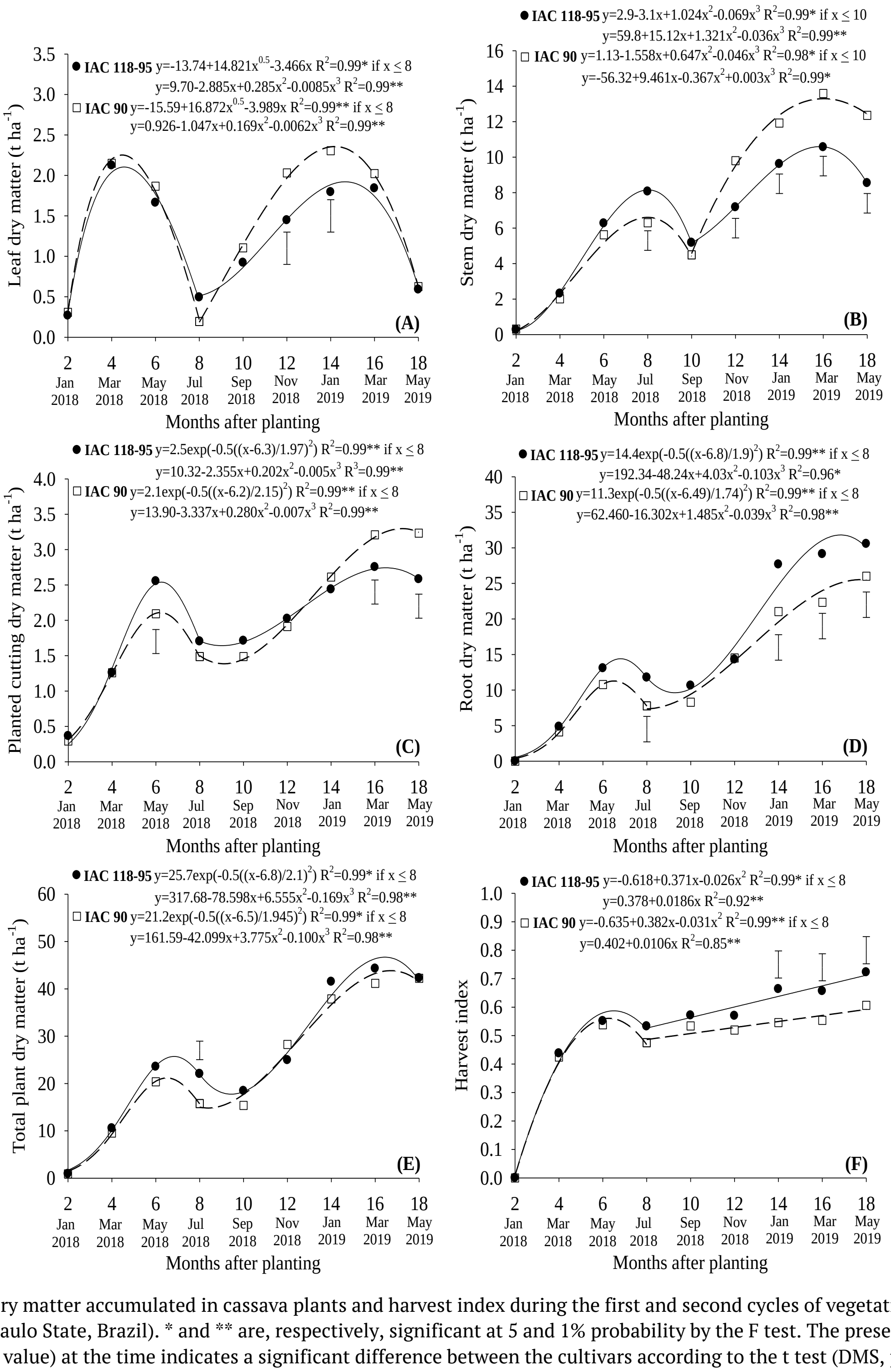

**Figure 3.** Dry matter accumulated in cassava plants and harvest index during the first and second cycles of vegetative growth. (Lupércio, São Paulo State, Brazil). * and ** are, respectively, significant at 5 and 1% probability by the F test. The presence of a vertical bar (DMS value) at the time indicates a significant difference between the cultivars according to the t test (DMS, $p < 0.05$).

In addition, TPFM and TPDM were negatively correlated with ash, protein and fibre content in roots in both cultivars, with positive correlation with starch content in leaves, stems and roots. Lipid levels in leaves and planted cuttings were negatively correlated with fresh and dry matter yields.

Differences between cultivars and plant age for dry matter yields are important in recommending the most suitable cassava cultivar for the chosen harvest age. This benefits farmers who can use this information to select specific cultivars to be harvested at different growing ages and thus prolong the root supply phase, even when planted at the same time. Being able to provide roots in long phases would stabilise income and would likely reduce the risk of suffering income losses during low-price phases (Enesi et al., 2022).

The chemical composition of cassava plants depends on the genotypes, age of the plant, area of cultivation, fertilisation practices, and environmental conditions (Morgan & Choct, 2016; Enesi et al., 2022).

**Table 1.** Correlation coefficients of total plant fresh matter yield (TPFM), total plant dry matter yield (TPDM), harvest index (HI) and root starch (RS) with growth parameters and chemical composition.

| | TPFM | | TPDM | | HI | | RS | |
|---|---|---|---|---|---|---|---|---|
| | 118-95 | 90 | 118-95 | 90 | 118-95 | 90 | 118-95 | 90 |
| LN | 0.73** | 0.76** | 0.60** | 0.68** | 0.39* | ns | ns | ns |
| SD | 0.55** | 0.74** | 0.48** | 0.75** | 0.35* | ns | 0.42* | 0.44* |
| PH | 0.78** | 0.75** | 0.78** | 0.80** | 0.78** | ns | 0.76** | 0.49** |
| LFM | ns | ns | ns | ns | ns | ns | -0.45* | -0.36* |
| SFM | 0.90** | 0.96** | 0.85** | 0.93** | 0.62** | ns | 0.71** | 0.66** |
| PCFM | 0.53** | 0.88** | 0.48** | 0.89** | ns | 0.51* | ns | 0.62** |
| RFM | 0.99** | 0.99** | 0.96** | 0.97** | 0.77** | 0.51* | 0.73** | 0.65** |
| TPFM | - | - | 0.95** | 0.97** | 0.73** | 0.44* | 0.71** | 0.63** |
| LDM | ns | ns | ns | ns | ns | ns | -0.42* | ns |
| SDM | 0.81** | 0.92** | 0.87** | 0.94** | 0.63** | 0.41* | 0.81** | 0.76** |
| PCDM | 0.73** | 0.89** | 0.76** | 0.93** | 0.62** | 0.48** | 0.62** | 0.71** |
| RDM | 0.93** | 0.94** | 0.99** | 0.98** | 0.80** | 0.52** | 0.78** | 0.73** |
| TPDM | 0.95** | 0.97** | - | - | 0.78** | 0.49** | 0.79** | 0.73** |
| HI | 0.73** | 0.44* | 0.78** | 0.49** | - | - | 0.84** | 0.62** |
| LA | ns | ns | 0.37* | ns | ns | ns | 0.49** | ns |
| SA | -0.38* | ns | ns | ns | ns | ns | ns | ns |
| PCA | -0.50* | -0.35* | -0.45* | ns | ns | ns | ns | ns |
| RA | -0.42* | -0.36* | -0.44* | ns | ns | ns | -0.38* | ns |
| LP | 0.37* | ns | ns | ns | 0.49** | ns | 0.36* | ns |
| SP | ns | ns | ns | ns | ns | ns | ns | ns |
| PCP | ns | -0.37* | ns | ns | ns | ns | ns | ns |
| RP | -0.52** | -0.51** | -0.42* | -0.48** | -0,42* | ns | ns | ns |
| LL | -0.53** | -0.64** | -0.42* | -0.56** | ns | ns | ns | ns |
| SL | ns | ns | ns | ns | ns | ns | ns | ns |
| PCL | -0.63** | -0.51** | -0.61** | -0.53** | -0.56** | ns | -0.42* | -0,39* |
| RL | ns | ns | ns | ns | ns | ns | ns | ns |
| LF | ns | ns | ns | ns | ns | ns | 0.42* | 0.43* |
| SF | 0.88** | 0.86** | 0.86** | 0.89** | 0.71** | 0.35* | 0.64** | 0.55** |
| PCF | ns | 0.59** | ns | 0.56** | 0.35* | 0.37* | ns | ns |
| RF | -0.39* | -0.47** | ns | -0.44* | ns | ns | ns | ns |
| LS | 0.89** | 0.74** | 0.88** | 0.78** | 0.65** | 0.52** | 0.64** | 0.77** |
| SS | 0.54* | 0.36* | 0.63** | 0.46** | 0.46** | ns | 0.76** | 0.74** |
| PCS | ns | ns | ns | ns | ns | ns | ns | 0.43* |
| RS | 0.71** | 0.62** | 0.80** | 0.73** | 0.84** | 0.62** | - | - |
| LTS | ns | ns | ns | ns | ns | -0.36* | ns | ns |
| STS | 0.54** | 0.59** | 0.54** | 0.58** | 0.41* | ns | ns | ns |
| PCTS | ns | ns | ns | ns | ns | ns | -0.51* | ns |
| RTS | ns | ns | ns | ns | ns | ns | ns | ns |

LN = leaf number; SD = stem diameter; PH = plant height; LFM = leaf fresh matter; SFM = stem fresh matter; PCFM = planted cutting fresh matter; RFM = root fresh matter; TPFM = total plant fresh matter; LDM = leaf dry matter; SDM = stem dry matter; PCDM = planted cutting dry matter; RDM = root dry matter; TPDM = total plant dry matter; HI = harvest index; LA = leaf ash; SA = stem ash; PCA = planted cutting ash; RA = root ash; LP = leaf protein; SP = stem protein; PCP = planted cutting protein; RP = root protein; LL = leaf lipids; SL = stem lipids; PCL = planted cutting lipids; RL = root lipids; LF = leaf fibre; SF = stem fibre; PCF = planted cutting fibre; RF = root fibre; LS = leaf starch; SS = stem starch; PCS = planted cutting starch; RS = root starch; LTS = leaf total sugars; STS = stem total sugars; PCTS = planted cutting total sugars; RTS = root total sugars. * = $p < 0.05$; ** = $p < 0.01$.

The ash content represents the amount of total minerals present in the parts of the cassava plant. The greatest translocation of minerals from the soil to the plant occurred in the initial growth stages, with higher ash content at 8 MAP, when 'IAC 90' differed with the highest content. After this increase, there was a decline in the physiological rest phase and a small increase at the beginning of the second vegetative cycle, with the ash content remaining constant until the final harvest (Figure 4).

The highest levels of ash were observed in the leaves, followed by the planted cutting, stems, and roots (Figure 4). Results obtained are within the range reported by Ferraro, Piccirillo, Tomlins, and Pintado (2016) for the levels of ash in the cassava leaves (0.7 to 4.5 g 100 $g^{-1}$) and roots (0.4 to 1.7 g 100 $g^{-1}$).

Soil characteristics, fertilisation practices, and climatic conditions are interfering factors for the ash content in plant parts, which may explain the lower levels observed in this study in relation to the results of five genotypes selected for industry in Uganda (1.05 to 2.39%) (Manano, Ogwok, & Byarugaba-Bazirake, 2018).

Cassava leaves had high levels of protein with the effect of harvest time (Figure 4). Younger leaves had the lowest levels. This result is in agreement with that of Ravindran and Ravindran (1988) who reported that crude protein decreased with an increase in plant age.

A previous study with five Brazilian cassava cultivars (Mico, Fibra, IAC 13, IAC 14, and Fécula Branca), showed that the protein content in leaves varied from 34.7 to 38.4% at 12 MAP, with a significant decrease at 21 MAP with variations ranging from 20.7 to 26.63% (Sagrilo, Otsubo, Silva, Rohden, & Gomez, 2007).

For the other parts of the plant, the highest protein content was observed at 8 MAP, i.e. at the end of the first vegetative cycle. However, at the beginning of the second cycle, the regrowth of shoots used the accumulated protein reserves in these parts of the plants. Consequently, the protein content decreased (Figure 4).

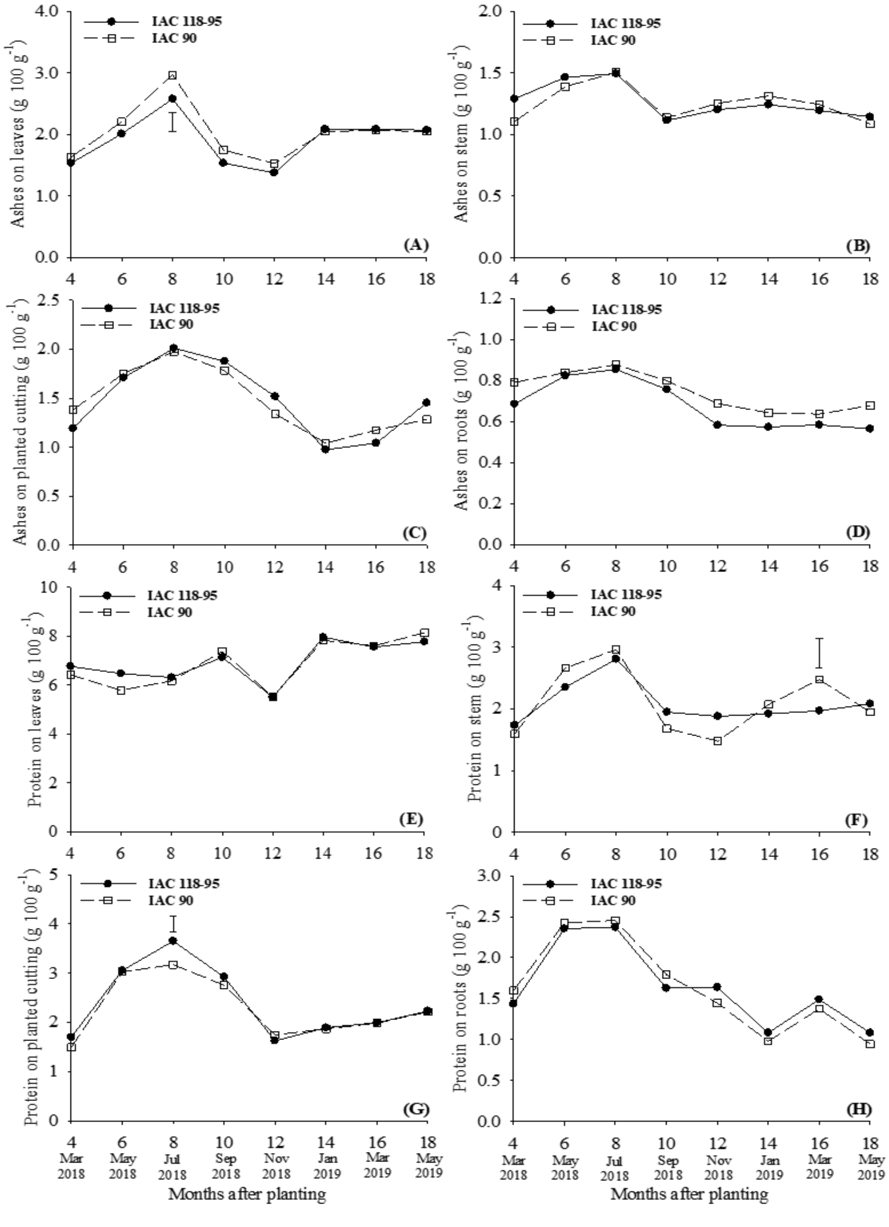

**Figure 4.** Ashes and protein contents in parts of the cassava plants during the first and second cycles of vegetative growth. (Lupércio, São Paulo State, Brazil). * and ** are, respectively, significant at 5 and 1% probability by the F test. The presence of a vertical bar (DMS value) at the time indicates a significant difference between the cultivars according to the t test (DMS, $p < 0.05$).

Cassava roots are not a good source of protein, especially the cultivars intended for industry. These cultivars are selected for greater starch accumulation. Morgan and Choct (2016) cited protein levels ranging from 0.7 to 1.3% (wet weight), similar to the results obtained in this study.

Lipids are the main components of cell membranes and have been related to the responses of plant organs to environmental conditions (Taiz, Zeiger, Møller, & Murphy, 2017). The leaves had the highest lipid levels at all harvest times (Figure 5). The highest levels were observed in young leaves during the initial period of shoot formation in the first cycle, coinciding with higher temperatures and rainfall. The same result was observed in the second cycle after 14 MAP. Differentiation between cultivars occurred in the stems and planted cutting during the physiological resting phase of the plants (Figure 5).

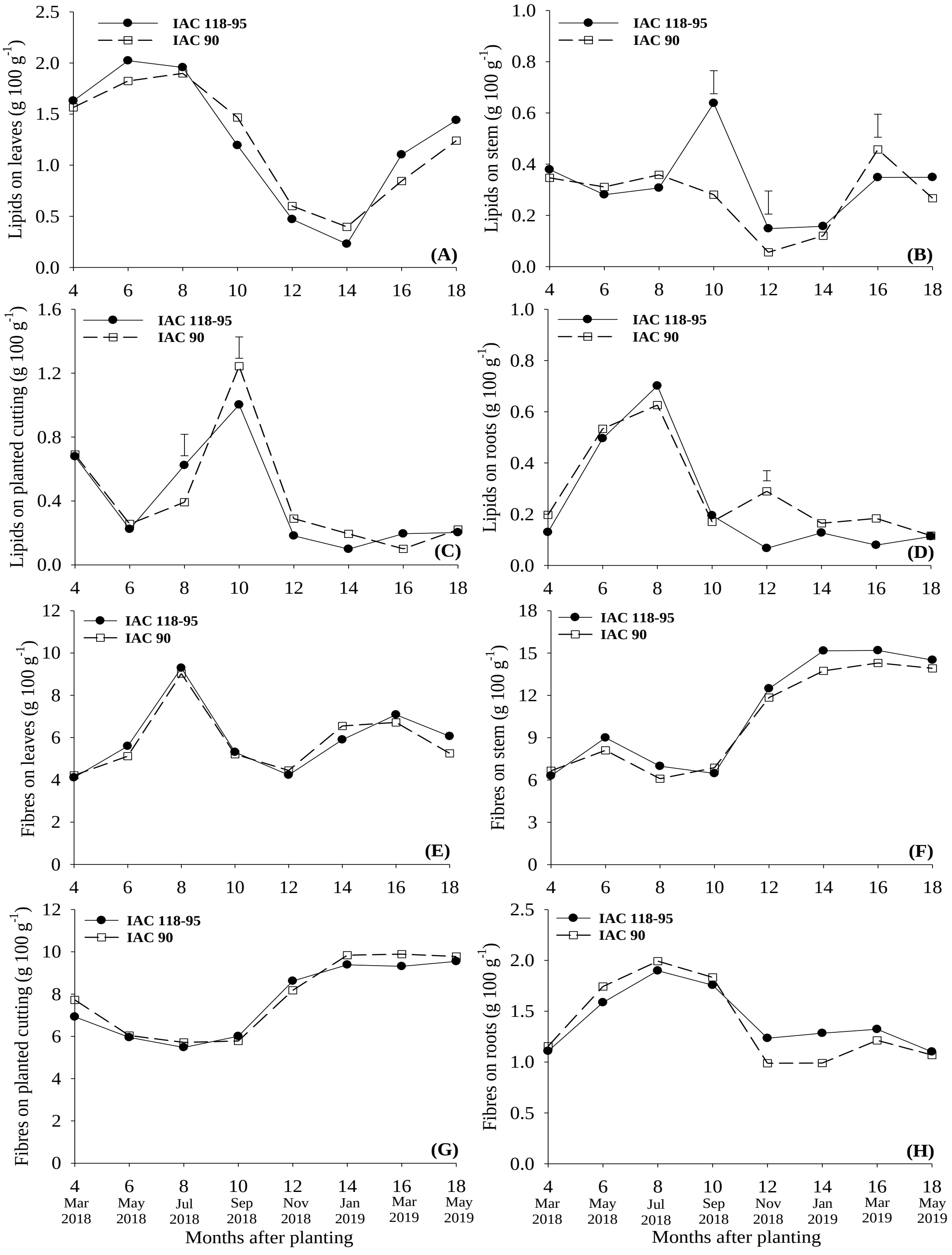

**Figure 5.** Lipids and fibres contents in parts of the cassava plants during the first and second cycles of vegetative growth. (Lupércio, São Paulo State, Brazil). * and ** are, respectively, significant at 5 and 1% probability by the F test. The presence of a vertical bar (DMS value) at the time indicates a significant difference between the cultivars according to the t test (DMS, $p < 0.05$).

Analysis of the total fibre content in the parts of the cassava plant showed that there is a significant increase in leaves with crop age, with a peak at 8 MAP in the first vegetative cycle and at 14-16MAP in the second cycle (Figure 5).

Stems and planted cuttings showed considerable fibre content, and as shoot pruning did not occur at the end of the first vegetative cycle, these contents were higher in the second vegetative cycle (Figure 5).

In the first vegetative growth cycle, cassava roots had a higher fibre content, which is related to the lower degree of tuberisation. In the second cycle, the fibre content was close to 1% for both cultivars. The decrease in fibre contents in tuberous roots during vegetative cycles was also reported by Pereira and Beléia (2004).

Analysis of the sugar content in the parts of the cassava plant showed the influence of harvest time on this component, with higher levels in the leaves and stems (Figure 6). In the planted cutting and roots, low levels were observed in the physiological rest phases, indicating that the plants obtained the necessary energy for this period in the starch reserves that were metabolised, resulting in increased levels of sugars in the planted cutting at the beginning of the second vegetative cycle (Figure 6).

The starch content in the plant parts was influenced by the crop age, with differentiation occurring between the cultivars at 16 MAP in the stems (Figure 6). During daytime photosynthesis, starch is synthesised from assimilated sugars and assembled into storage granules in specific tissues (leaves, stems, planted cuttings, and roots) (Taiz et al., 2017).

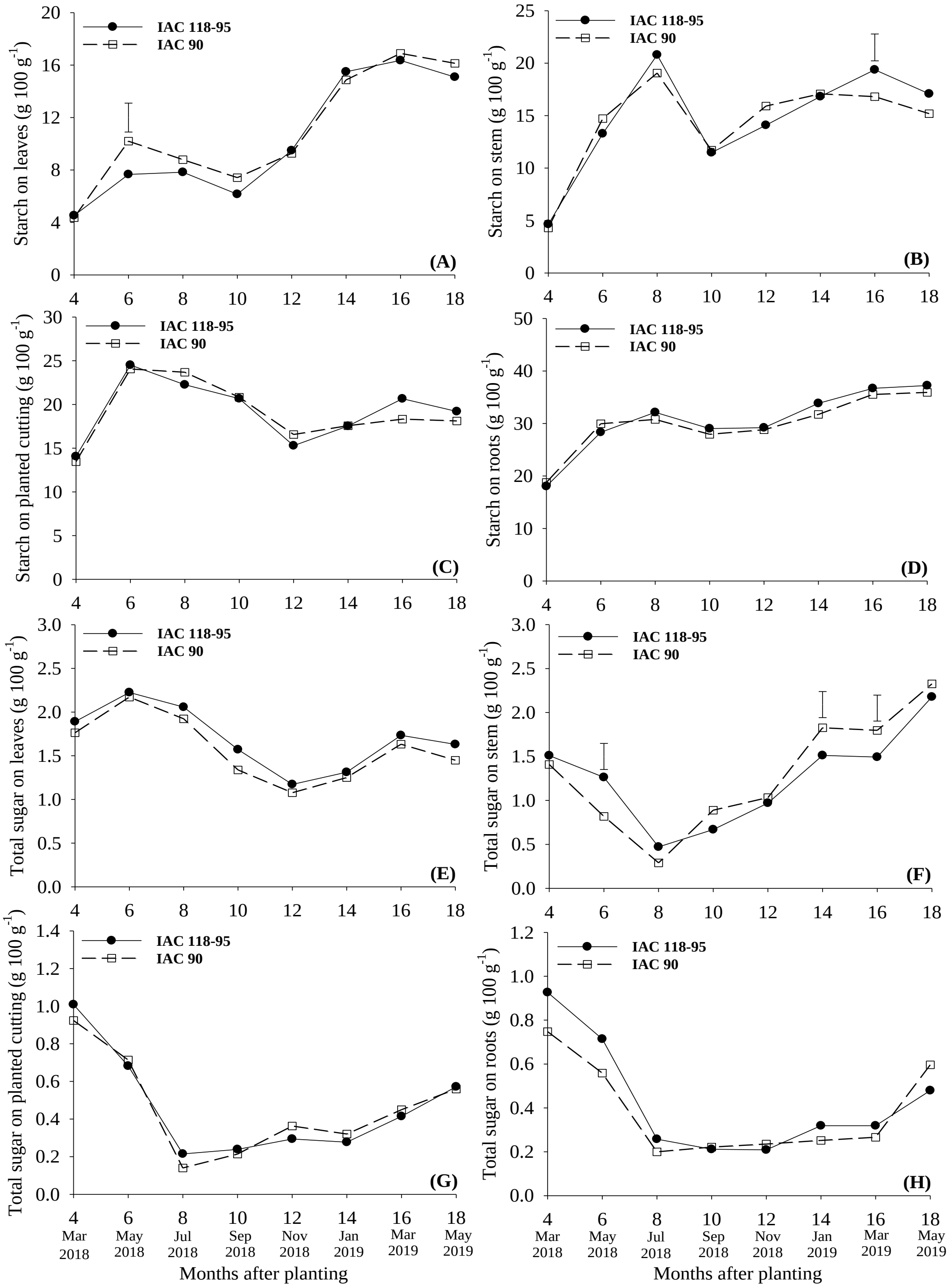

**Figure 6.** Starch and total sugars contents in parts of the cassava plants during the first and second cycles of vegetative growth. * and ** are, respectively, significant at 5 and 1% probability by the F test. The presence of a vertical bar (DMS value) at the time indicates a significant difference between the cultivars according to the t test (DMS, $p < 0.05$).

In the first vegetative growth cycle, the leaves had lower levels of transient starch than in the second cycle, when there was greater shoot growth and higher levels of starch in the leaves and a decrease in the older leaves (18 MAP; Figure 6)

Photosynthetic assimilation of $CO_2$ by leaves produces sucrose in the cytosol and starch in the chloroplasts. During the day, sucrose flows into the draining tissues and starch accumulates in the chloroplasts. At night, $CO_2$ assimilation ceases and starch degradation occurs in chloroplasts. Thus, carbon metabolism in leaves responds to the energy and growth needs of the draining tissues (El-Sharkawy, 2003; Taiz et al., 2017).

Changes in starch levels in parts of the cassava plant also showed the interference of climatic conditions during growth cycles (Figures 1 and 6). Cassava has an efficient photosynthesis mechanism. It shows less saturation of photosynthesis with high irradiance and maintenance of photosynthesis at leaf temperatures above 30°C (Souza et al., 2017; Tappiban, Smith, Triwitayakorn, & Bao, 2018). In addition, cassava can be considered resistant to drought because of its ability to accumulate substantial reserves of carbohydrates in its stem, which are slowly remobilised during episodes of stress (Connor, 2019; Duque & Setter, 2019).

Starch content in cassava roots ranged from 18 to 37%, with no difference between cultivars at all harvest times (Figure 6). However, when we observed the differentiation between the cultivars for the production of dry matter in the second vegetative cycle, the productivity in tons of starch per hectare of ‘IAC 118-95’ was higher, which is important for the indication of this cultivar for the industries.

Fresh and dry matter yields of cassava plant were negatively correlated with ash, protein and fibre content in roots in both cultivars, with positive correlation with starch content in leaves, stems and roots.

For both cultivars starch content in roots was positively correlated with plant height, stem diameter, total plant fresh and dry matter yields. Moreover, starch accumulation in roots was negatively correlated with leaf fresh matter (Table 1).

In addition to the parameters of productivity and resistance to pests and diseases in the selection of cultivars for the starch industry, another important aspect is the low content of non-starch components in the roots. This is due to the fact that in industrial processing, starch quality is intrinsically linked to lower percentages of proteins, fibre, ash, and sugars (Fernandes, Santos, Fernandes, & Leonel, 2019). For both cultivars, older plants had lower levels of these components in the roots starting from 12 MAP (Figures 4 to 6).

With the possibility of early harvest from 14 MAP, the considerable number of leaves on the plants could add value to them as a by-product of the starch processing industry (Figure 2). In Brazil, there is no tradition of the industrial processing of cassava leaves. The Brazilian North and Northeast regions have a traditional product, the “Maniçoba”, a type of cassava soup that uses crushed leaves boiled in water for several days to eliminate $CN^-$. Another use of cassava leaf is as a food supplement (‘Multimistura’). It is flour composed of food by-products that are used to combat malnutrition in poorer populations (Latif & Muller, 2015; Leonel, Garcia, Santos, Fernandes, & Mischam, 2019; Moraes, Campos, Araújo, Lopes, & Pena, 2021). Planning harvests according to the different ages of the plant can also favour a balance between high levels of proteins and minerals in the leaves and lower levels of fibre, which can act as an anti-nutritional factor (Latif & Muller, 2015).

## Conclusion

This work demonstrated that the cassava cultivars differed for fresh and dry matter yields in plant parts. The cultivar IAC 118-95 presents better harvest index and allows early harvests. Harvests at the end of the first cycle should be analyzed economically to compensate for lower yields. The differences observed between cultivars and crop age showed that there is potential to recommend the most suitable cassava cultivar for the chosen cropping season.

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