Universidade Federal Rural do Semi-Árido
Pró-Reitoria de Pesquisa e Pós-Graduação
https://periodicos.ufersa.edu.br/index.php/caatinga

ISSN 0100-316X (impresso)
ISSN 1983-2125 (online)
http://dx.doi.org/10.1590/1983-21252022v35n223rc

GROWTH ANALYSIS AND PHOTOASSIMILATED PARTITION IN ARROWROOT PLANTS IN ORGANIC CROP SYSTEM[1]

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ABSTRACT – Arrowroot (*Maranta arundinaceae*), a traditional plant used to extract medicinal starch that is gluten-free and of excellent nutritional quality, is understudied for its growth and development in the organic crop system. The objective of this study was to evaluate the growth and photoassimilate partitioning in plants of two cultivars, Comum and Seta arrowroot. The design was performed in random blocks with four repetitions. At 57 days after planting (DAP), the plants were collected at regular intervals of 25 days throughout the crop cycle, and the dry mass was determined. Growth analysis was performed using the primary data. The cultivars Comum and Seta show maximum absolute growth rates of 10.51 and 12.42 g plant^{-1} day^{-1} and the maximum leaf area index (LAI) of 18.74 and 14.62, as recorded for 216 and 205 DAP, respectively. The higher absolute growth rate and higher growth of arrowroot plants in a shorter time indicate greater precocity of cultivar Seta compared to Comum. The photoassimilate partitioning is balanced between the aerial parts and rhizomes at the end of the cycle. Both cultivars can be recommended for the organic crop system in the Zona da Mata region of Minas Gerais.

Keywords: *Maranta arundinacea* L. Growth stages. Leaf area index. Cultivars.

ANÁLISE DE CRESCIMENTO E PARTIÇÃO DE FOTOASSIMILADOS EM PLANTAS DE ARARUTA EM SISTEMA DE CULTIVO ORGÂNICO

RESUMO - A araruta (*Maranta arundinaceae*) planta tradicional usada para extração de fécula de excelente qualidade nutricional, medicinal e isenta de glúten, é pouco estudada quanto ao seu crescimento e desenvolvimento em cultivo orgânico. Esse trabalho teve por objetivo avaliar o crescimento e a partição de fotoassimilados em plantas de duas cultivares de araruta Comum e Seta. O delineamento foi em blocos ao acaso, com quatro repetições. A partir de 57 dias após o plantio (DAP), as plantas foram coletadas a intervalos regulares de 25 dias ao longo do ciclo de cultivo, sendo determinados a massa seca. A partir dos dados primários, foi aplicada a análise de crescimento. As cultivares Comum e Seta tiveram taxa de crescimento absoluto máximos de 10,51 e 12,42 g planta^{-1} dia^{-1} e IAF máximos de 18,74 e 14,62, alcançados com 216 e 205 DAP, respectivamente. A maior taxa de crescimento absoluto e o maior crescimento de plantas de araruta num tempo mais curto indicam maior precocidade da cultivar Seta em relação à Comum. A partição de fotoassimilados é equilibrada entre a parte aérea e os rizomas no final do ciclo. As duas cultivares podem ser recomendadas para o sistema de cultivo orgânico na região da Zona da Mata de Minas Gerais.

Palavras-chave: *Maranta arundinace* L. Estágios de crescimento. Índice de área foliar. Cultivares.

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INTRODUCTION

Arrowroot (*Maranta arundinacea*) is a species whose commercial importance is related to the production of rhizomes, which contain high levels of starch with excellent nutritional quality, and are used in the preparation of many food products such as biscuits, cakes, porridge, and sweets. Rhizomes contain about 24.23% starch, 1.08% total soluble sugars, 0.85% reducing sugars, 1.44% fiber, and 1.34% protein (LEONEL; CEREDA, 2002); being gluten-free, they are also recommended for people who are intolerant to this protein. Thus, the advantage of arrowroot starch is its high nutritional value and absence of gluten making it an excellent raw material for producing dietary supplements for patients suffering from Celiac disease (GUILHERME et al., 2019). The starch content in arrowroot rhizomes can vary with the crop cycle (FERRARI; LEONEL; SARMENTO, 2005; AMANTE et al., 2020) and with the cultivar (SOUZA et al, 2019a; SOUZA et al., 2019b).

Brazil has faced difficulties over arrowroot planting in large areas due to the lack of seedlings, productive genotypes, and planting and harvesting technologies. As the arrowroot plant is considered an unconventional vegetable, it has received little attention in research, limiting the agronomic knowledge of the crop. However, in recent years, this vegetable has shown an increased presence in the market for its quality starch. We need more studies to rescue and develop arrowroot cultivation in farming fields and as an alternative to family farming. Some studies have focused mainly on crop management systems and plant nutrition (SANTOS; CEREDA; GUILHERME, 2019), and more research is needed to understand the phenological cycle and phytotechnical aspects of the crop.

Knowledge of the crop's phenological cycle is significant for planning the agronomic calendar and adjusting cultivation practices according to the physiological events of arrowroot under favorable environmental conditions. In a greenhouse study, Brito et al. (2019) presented the eight main stages observed in the growth of arrowroot plants: sprouting, development of the main stem and leaves, tillering, elongation of the main stem, rhizome formation, emergence of inflorescence, flowering, and leaf senescence. These observations were made using the BBCH (Biologische Bundesanstalt Bundessortenamt und Chemische Industrie) scale system, which proposes a decimal code system to describe the major phenological events during the plant life cycle.

Studies focusing on the growth stages of all arrowroot plant varieties are fundamental in promoting further research, as there is no information on the phenology of the crop under field conditions and in organic crop systems. This work contributes towards understanding the productive characteristics, thereby improving the cultivation conditions and product supply in addition to stimulating consumption habits. Thus, the objective of this study was to evaluate the growth and photoassimilate partition in plants of two arrowroot cultivars, Comum and Seta, in field conditions and organic crop systems.

MATERIALS AND METHODS

The study was conducted from October 2016 to August 2017 at the Vale do Piranga Experimental Field (EPAMIG) in Oratorios, Minas Gerais. The study area is located at 20°30 S and 43°00W, at an average altitude of 500 m above sea level. The climate is mild, with an average annual maximum temperature of 21.8°C and an annual minimum temperature of 19.5°C, with hot summers. The annual average rainfall is 1,250 mm. However, during the experimental period, the accumulated and recorded rainfall was 934.80 mm.

The soil used in the experiment was Cambic Red-Yellow Argisol, terrace phase, clayey texture, with the following characteristics in the 0-20 cm layer: pH (water 1:2,5)=6.1; organic matter= 2.6 dag kg^{-1}; P=26.9 mg dm^{-3}; K=290 mg dm^{-3}; Ca^{2+}=2.4 $cmol_c$ dm^{-3}; Mg^{2+}=1.2 $cmol_c$ dm^{-3}; Al^{3+}=0.0 $cmol_c$ dm^{-3}; H+Al=2.1 $cmol_c$ dm^{-3}; SB=3.98 $cmol_c$ dm^{-3}; CEC (t)=4.3 $cmol_c$ dm^{-3}; CEC (T)=6.4 $cmol_c$ dm^{-3}; V=75% and m=0.0%. According to the results of the soil chemical analysis, liming for pH correction was not required. The tillage consisted of plowing, harrowing, and furrowing at a depth of 30 cm. Fertilization was done using 30.0 t ha^{-1} of tanned bovine manure and split into two applications: 2/3 in the furrow before planting, and 1/3 in topdressing at 50 days after planting (DAP).

The arrowroot rhizomes were planted on 10/10/2016 in furrows of approximately 3.0 cm depth. Spacing was 0.80 m between rows and 0.40 m between plants in the row, with 960 plants in the experimental area. The plot area was 76.8 m^2 (4.8 x 16.0 m), with 240 plants and 120 plants of each cultivar distributed in six rows of 16.0 m in length. The experimental design was a randomized complete block in a factorial scheme 2 x 9 that consisted of two arrowroot cultivars Comum and Seta, nine harvest periods, and four replications.

At each harvest, four useful plants from each cultivar were removed per replicate. Harvesting started 57 days after planting (DAP) and was performed every 25 days during the entire plant ontogeny. The last harvest was performed at 275 DAP when the plants were 10 months old and practically senescent. The plants were removed using a hoe and placed in plastic boxes. Next, the rhizomes and roots were washed in running water to remove all the adhered soil. After washing, the plants were transported to the laboratory where they were separated into leaves, tillers, roots, and rhizomes for further analysis.

The public domain ImageJ® Software (Image Processing and Analysis in Java) (RASBAND, 2016), which captures the image of each leaf with color contrast procedures was used to calculate leaf area. In this procedure, the dark-colored leaf was contrasted with the background, and the actual total area of the leaf was calculated in comparison with the real scale. The leaf area index (LAI) was calculated using the formula: LAI = LA / S, where LA is the leaf area (m^2) and S is the available area for the plant (m^2).

The fresh mass of leaves, petioles, tillers, and roots was obtained by weighing all parts of each plant. Subsequently, the dry mass was determined using a precision balance after drying to a constant weight in a forced-air oven at 65 °C. From 120 DAP, rhizomes began to appear, and they were also evaluated for fresh and dry masses.

Data on the dry mass were subjected to regression analysis, in which the plant age, expressed in days after planting, was the independent variable. Plant growth was characterized by dry mass (DM) of leaves, petioles, tillers, rhizomes, aerial parts (leaves + petiole + tillers), and whole plants (aerial part + rhizomes). The primary data of the accumulated total dry mass (Wt) were adjusted using the equation $Wt = exp (A - Bx - C/x^2)$; $Wt = exp (A - B/x^2)$ or Wt = A. (1 + exp (B - Cx)) and the absolute plant growth rate (Cw) by the first derivative of the Wt-adjusted equation with respect to time. To determine the instantaneous values of the relative growth rate (Rw), the following formula was used: Rw = (1/Wt). (dw/dt). Total dry mass (Wt) was determined by adding the dry mass of leaves (Wf), petiole + tillers (Wp), roots, and rhizomes (Wrz). The dry mass of the aerial part (Wpa) was obtained from the sum of Wf and Wp.

RESULTS AND DISCUSSION

During the plant growth evaluation, three growth phases were observed in both cultivars. These phases were defined as a function of the percentage of total dry mass accumulation (Wt), represented by Phase I (up to 10% of Wt), Phase II (from 10 to 50% of Wt), and Phase III (from 50 to 100% of Wt). The Wt value was obtained at harvest of the rhizome (Figure 1).

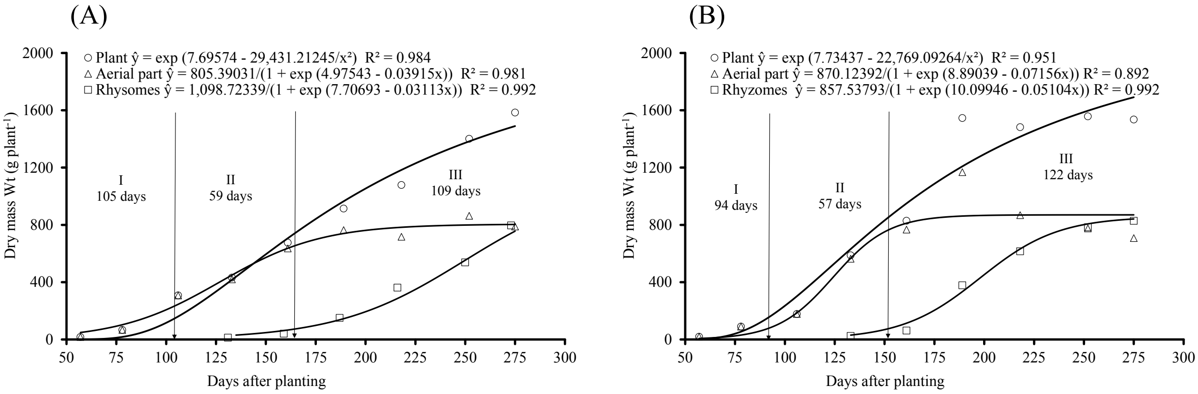

Figure 1. Mass accumulation of the dry mass of the aerial part, rhizomes, and total plant in two cultivars of Arrowroot, Comum (A) and Seta (B) in field conditions.

The duration of growth phases differed between cultivars. Phase I lasted 105 and 94 DAP (Figure 1) and at the end of this phase, the absolute growth rate (Cw) was 7.75 and 9.53 g $plant^{-1}$ day^{-1} for ‘Comum’ and ‘Seta’, respectively (Figure 2). Phase I involves emergence, early tillering, and plant growth, being shorter and with higher Cw for ‘Seta’. This phase coincides with stages 1, 2, and 3 of arrowroot development observed by Brito et al. (2019) using the BBCH scale system.

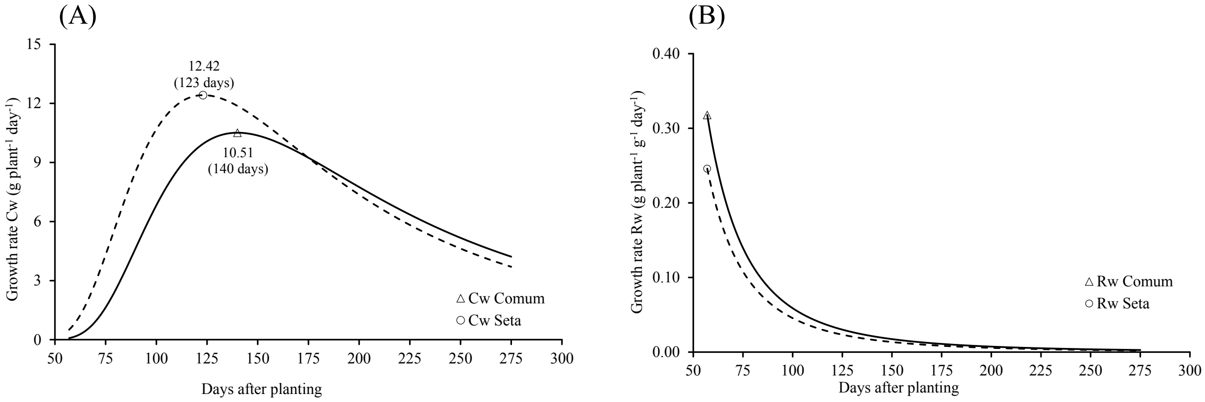

Figure 2. Cw - Absolute growth rate (A) and Rw - relative growth rate (B) in two Arrowroot cultivars, Comum and Seta during plant growth in field conditions.

Phase II lasted 59 and 57 days for 'Comum' and 'Seta', respectively, with less time variation (Figure 1). The Cw maximum was estimated in the middle of this phase at 10.51 and 12.42 g plant^{-1} day^{-1} for 'Comum' and 'Seta', respectively. This phase was shorter and similar for both cultivars, but the highest Cw was observed throughout the cycle (Figure 2A), as the aerial part and rhizome of the plants continued to grow (Figure 1). In this phase, the first rhizomes began to appear (Figure 1). The strength of the plant drain was altered due to the predominant growth of the reserve organs, which increased the photoassimilate translocation from the leaves to the rhizomes, as observed by Brito et al. (2019) at stages 4, 5, and 6 on the BBCH scale.

Phase III corresponds to the highest accumulation of dry mass by plants (50%–100%) lasting 109 and 122 days for 'Comum' and 'Seta', respectively (Figure 1). The plants continued to grow until 275 DAP when harvesting was carried out. Such growth occurred as Cw decreased daily until reaching 100% of Wt (Figures 1 and 2). At this stage, the reduction in growth is caused by the continuous change in the source/drain ratio that started at the end of Phase II, as observed at stage 9 of development on the BBCH scale (BRITO et al., 2019).

The Cw, in cultivars Comum and Seta, increased until 140 and 123 days, with maximum values of 10.51 and 12.42 g plant^{-1} day^{-1}, respectively (Figure 2A). Combined with shorter periods of Phases I and II (Figure 1), 'Seta' demonstrated greater growth thus, confirming a slight precocity over 'Comum'.

The relative growth rate (Rw) curves revealed that arrowroot plants showed typical behavior, high at the beginning, with subsequent fall throughout the cycle (Figure 2B). Variation was observed in the maximum value of Rw, estimated at 0.318 and 0.246 g plant^{-1} day^{-1} for 'Comum' and 'Seta', respectively. Thus, 'Comum' demonstrated greater efficiency in dry mass allocation compared to that first contained in 'Seta'. Arrowroot seedlings are rhizomes of plants and have a large amount of reserve material; however, there may be differences between cultivars due to the size of the seedling. Moreover, at the beginning of the cycle, 'Comum' had a higher leaf area index (LAI) than 'Seta' (Figure 3A), so young 'Comum' leaves could have the higher photosynthetic capacity, despite the lower growth rate values (Figure 2A). Young plants which have leaves with high photosynthetic capacity and high growth rate show higher Rw values (MARTINAZZO et al., 2015). According to Benincasa (2003), the decrease in Rw throughout the cycle is a result of the gradual increase in non-photosynthetic tissues, due to the rise in respiratory activity, variations in climatic conditions, and self-shading that can be observed due to the increase in leaf area.

The development stage of arrowroot plants directly influences the physicochemical characteristics of rhizomes and the extracted-starch fraction (FERRARI; LEONEL; SARMENTO, 2005). Studies also state that arrowroot rhizomes should be harvested for starch extraction 12–14 months after planting. When working with the arrowroot cultivar Comum in pot cultivation, Guilherme et al. (2016) suggested that the harvest should be done after 210 days of planting, after which the arrowroot reaches its full phenological development, producing a greater number of rhizomes and consequently achieving higher productivity.

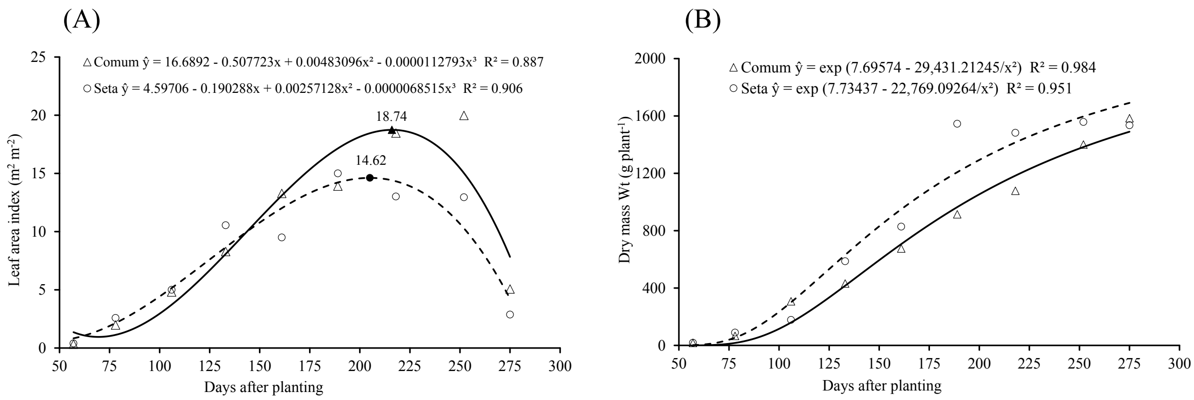

Figure 3. Leaf area index (A) and dry mass accumulation in whole plant (B) in two Arrowroot cultivars, Comum and Seta in field conditions.

The LAI was significantly higher in the Comum cultivar compared to Seta, with estimated maximum values of 18.74 and 14.62 at 220 and 205 DAP, respectively (Figure 3A). These values increased slowly with plant growth and decreased during the last evaluation. Increment in the leaf area may lead to self-shading, and throughout the cycle, non-photosynthetic tissues gradually increase due to an increase in respiratory activity and consequent reduction in plant growth (BENINCASA, 2003). The reduction in LAI at the end of the cycle is a common feature in growing plants such as arrowroot, as it is associated with reduced useful leaf area with the onset of plant senescence and leaf death. The growth of rhizomes, as strong metabolic drains and with great power to mobilize assimilates, accelerates leaf senescence, which consequently reduces LAI (CONCEIÇÃO; LOPES; FORTES, 2004).

The leaf area is related to the final production of the dry mass because during the development cycle, the plant depends on the leaves as photosynthetic organs and the plant growth rate depends on both the leaf area expansion rate and the photosynthetic rate per leaf area unit (TAIZ et al., 2017). However, the Seta cultivar produced more dry mass than the Comum cultivar. The Wt maximum was estimated at 1,490 and 1,691 g plant^{-1} at 275 DAP for 'Comum' and 'Seta', respectively (Figure 3B). The Seta cultivar showed lodging of its aerial part and the 'Comum' remained erect longer, allowing better light absorption by the leaves, thus favoring dry mass accumulation by the plants and delaying lodging under study conditions. These characteristics result in greater rhizome production, which does not occur. Thus, the Seta cultivar is more efficient at accumulating photoassimilates in the whole plant.

Dry mass accumulation was slow until 105 DAP (Comum) and 94 DAP (Seta), with a small difference between cultivars. From this time onward, dry mass accumulation increased rapidly in 'Seta', remaining higher than 'Comum' until the end of the cycle (Figure 1). Slow growth in the early stage is observed as a function of utilization of the reserves in the seed rhizomes, as for sweet potato, potato, taro, and other vegetatively propagated species. As the plants have smaller root volumes, the rate of water and nutrient absorption is lower, causing smaller leaf area and reduced net assimilation rate and respiration rate (CONCEIÇÃO; LOPES; FORTES, 2004; FERNANDES et al., 2010; OLIVEIRA; ARAÚJO; GUERRA, 2011).

Accumulation in the dry mass of leaves (Wl), petiole + tillers (Wp), aerial parts (Wap), rhizomes (Wrz), and whole plants (Wt) showed exponential functions. The maximum estimated Wl was 235 g plant^{-1} and 243 g plant^{-1} at 194 DAP and 178 DAP for cultivars Comum and Seta, respectively (Figure 4A). From this point, leaf dry mass accumulation was reduced until the end of the cycle. Both cultivars showed similar leaf growth throughout plant development, in which Seta was slightly faster. The reduction in leaf dry mass accumulation is characterized by a reduction in the emission of new leaves and the natural senescence of the existing ones, thereby determining the plant maturity index and/or harvest point. Guilherme et al. (2016) reported a decrease in the average number of arrowroot leaves after 150 days and justified this reduction with leaf senescence, which corroborates the reduction in leaf dry mass in this study.

The Wp maximum was estimated at 639 g and 765 g plant^{-1} at 275 and 201 DAP, for cultivars Comum and Seta, respectively (Figure 4B). And the highest Wap estimated was 815 g plant^{-1} and 1,005 g plant^{-1}, which occurred at 275 and 194 DAP, for cultivars Comum and Seta, respectively (Figure 4C). The higher dry mass accumulation in the aerial part of 'Seta' compared to 'Comum' demonstrated the higher vigor of the plants, as observed by Pereira (2019) in a conventional crop system.

The earlier maximum accumulation of leaf

(Wl), petiole (Wp), and aerial part (Wap) dry mass in ‘Seta’ (178, 201, and 194 days, respectively) demonstrated its greater precocity based on its shorter time of achieving maximum accumulation. Dry mass accumulation during growth is initially slow, followed by the phase of the greatest accumulation. Finally, in the phase of decline, rhizomes emerge due to the high mobilization capacity of assimilates and nutrients. The rhizomes become preferential metabolic drains causing a reduction in the accumulation of the dry mass of the aerial part, as observed by Pereira (2019) for the same cultivars of arrowroot.

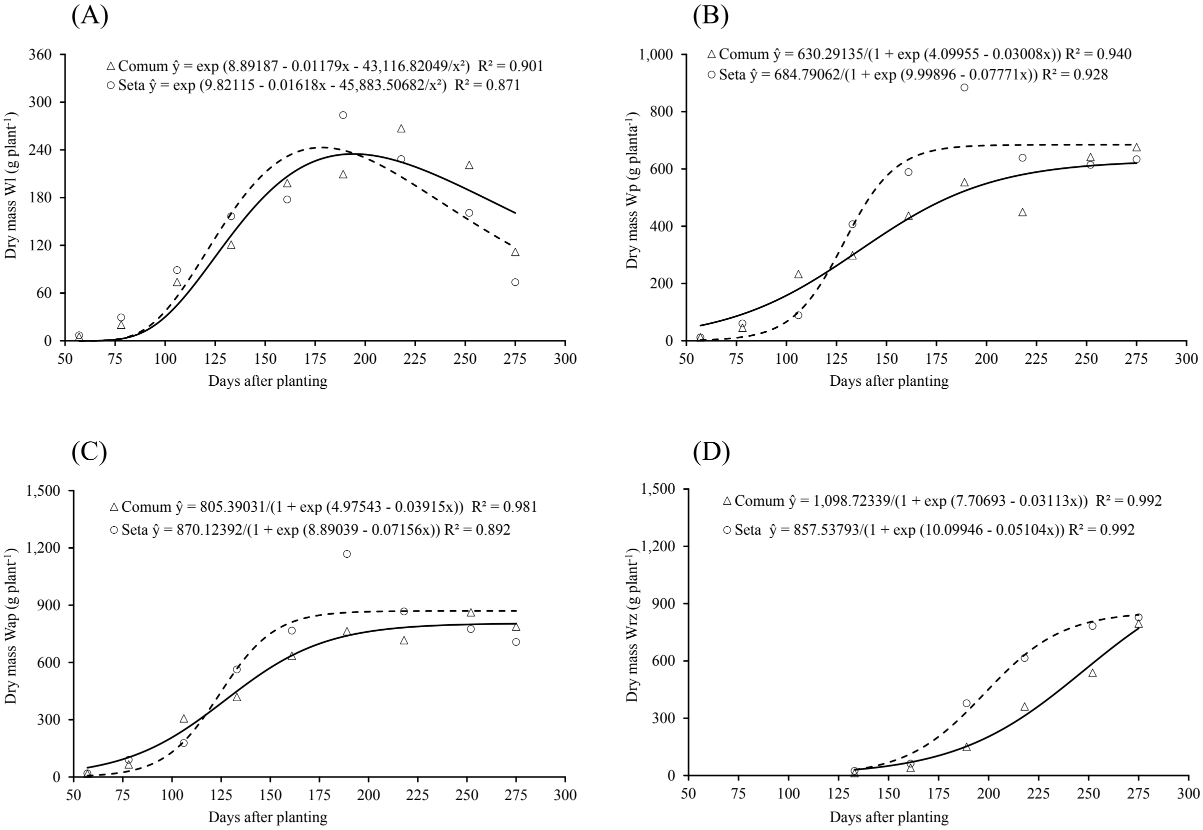

Figure 4. Dry mass accumulation in leaves (A), petioles (B), aerial part (C), and rhizomes (D) in two Arrowroot cultivars, Comum and Seta in field conditions.

The highest dry mass accumulation was found in the rhizomes, and the Wrz maximums were estimated at 773 g $plant^{-1}$ and 819 g $plant^{-1}$ at 275 and 267 DAP, for cultivars Comum and Seta, respectively (Figure 4D). Dry mass accumulation in rhizomes was potentially increased until the end of the cycle for the same cultivars (PEREIRA, 2019) and the ‘Seta’ cultivar showed higher dry mass accumulation than ‘Comum’. Rhizomes are reserve organs of arrowroots from which starch of high nutritional and commercial value is extracted. The cultivar Seta was faster and more productive in terms of dry mass accumulation in rhizomes, than ‘Comum’. The starch content in arrowroot rhizomes can vary with the cultivar, 'Seta' had 11.32% (SOUZA et al, 2019a) and that for 'Comum' was 20.28% (SOUZA et al., 2019b) and the crop cycle (18 – 23%) (FERRARI; LEONEL; SARMENTO, 2005; AMANTE et al., 2020). Thus, it is expected that 'Comum' arrowroot plants (156.76 g $plant^{-1}$) can produce a far higher amount of starch than 'Seta' (92.71 g $plant^{-1}$). Estimates show that 4.9 t ha^{-1} and 2.9 t ha^{-1} of starch would be produced with the cultivars Comum and Seta, respectively, with a population of 31,250 plants ha^{-1} in the organic crop system. These values are higher than those estimated by Pereira (2019) for 'Comum' (2.5 t ha^{-1}) and 'Seta' (3.0 t ha^{-1}) in the conventional crop system with a population of 33,333 plants ha^{-1}.

The characteristics evaluated in this study were efficient in showing differences between arrowroot cultivars. They highlight the precocity of

'Seta' as it presented a higher absolute growth rate of the plant (12.42 g plant^{-1} day^{-1}) and a shorter time in the first two growth phases. The 'Comum' cycle is longer as it has a lower growth rate (10.51 g plant^{-1} day^{-1}), which means that it needs more time to reach the end of the cycle.

The competition for photoassimilates among drains and source affects the growth rate of the plant and the production of rhizomes, the main drain for arrowroot plants. An increase in the number of rhizomes in the plant may increase the amount of photoassimilates allocated to the rhizomes at the expense of vegetative growth, as seen in plants with fruit as the main drain (MARTINAZZO et al., 2015; VIDIGAL; PUIATTI; SEDIYAMA, 2021). It was observed that the two cultivars followed the same pattern of photoassimilate partitioning among the aerial parts (leaves and petioles) and rhizomes, the commercial product of arrowroot. At the end of the cycle, the rhizomes accumulated 50% and 54% of the dry mass for the Comum and Seta cultivars, respectively (Figure 5). However, the precocity of the Seta cultivar indicated that at 252 DAP, an accumulation of 50% of rhizome dry mass was reached.

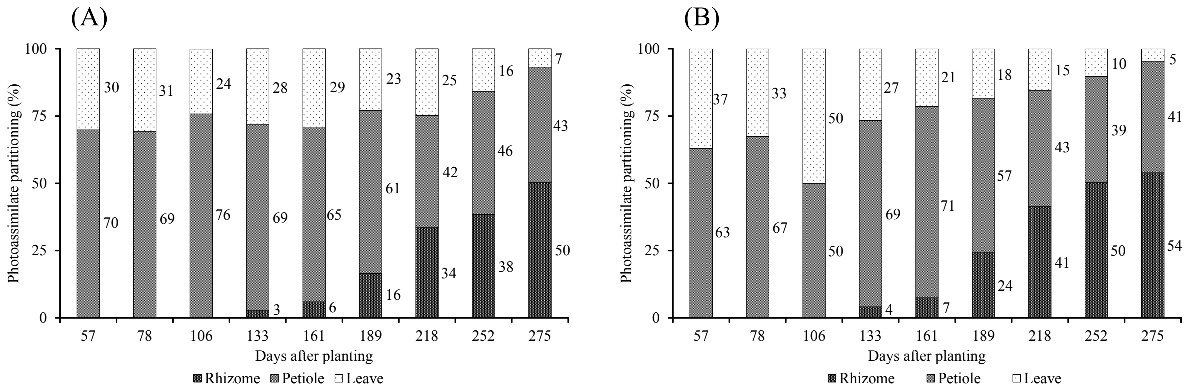

Figure 5. Photoassimilate partitioning in the plant of two cultivars of Arrowroot, Comum (A) and Seta (B) in field conditions.

Differences in cycle length were observed between cultivars, i.e., rhizomes of Comum can be harvested at 9 to 10 months after planting; harvesting for Seta may occur a little earlier at 8-10 months for the conditions in Oratorios, Minas Gerais. This result corroborates the existing literature, which shows that the harvest time depends on the cultivar, type of management, and region of cultivation.

CONCLUSIONS

The highest absolute growth rate (Cw) and highest plant growth of arrowroot in a shorter time indicate a greater precocity of the Seta cultivar than Comum.

The photoassimilate partitioning is balanced between the aerial parts and rhizomes at the end of the cycle.

The two cultivars can be recommended for organic crop systems in the Zona da Mata region of Minas Gerais.

ACKNOWLEDGEMENTS

We thank the Research Support Foundation of the state of Minas Gerais (Fundação de Amparo à Pesquisa do Estado de Minas Gerais (FAPEMIG) for financially supporting the study and the BIPDT and PIBIC fellowships.

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