Influence of the limitation of axillary bud growth on grain and oil yield of castor bean hybrids

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ABSTRACT

Cycle reduction and uniform fruit maturation are desired characteristics for a mechanical harvest of castor bean crop. The objective of this research was to study the effect of secondary growth limitation on growth and production parameters of castor bean plants. A field experiment was conducted between February and May 2012 in a randomized block design in a factorial scheme 2 × 2, with four replications. Two castor bean hybrids (Hybrid 12 and Hybrid 18) were grown in two cultivation systems: (i) plants without growth limitation and (ii) plants with secondary stem growth limitation (thinning with pruning). Removal of secondary stems resulted in higher partitioning of assimilates to the primary raceme, promoting higher number and dry weight of grains. As a result, plants with only the primary raceme presented grain yield equivalent to plants without growth limitation. Oil yield of plants with only the primary raceme was equivalent to the control for the Hybrid 12 and higher for the Hybrid 18, with advantage of uniform maturation for these plants.

Keywords: *Ricinus cummunis* L; source-sink relationship; plant management.

RESUMO

Influência da limitação do crescimento de gemas axilares sobre a produtividade de grãos e óleo de híbridos de mamona

Redução no ciclo e uniformidade na maturação de frutos são características desejadas para a colheita mecanizada da cultura da mamona. O objetivo do presente trabalho foi estudar o efeito da limitação do crescimento secundário sobre o crescimento e os parâmetros produtivos da mamona. O experimento de campo foi conduzido entre fevereiro e maio de 2012, em delineamento experimental de blocos casualizados e esquema fatorial 2x2, com quatro repetições. Dois híbridos de mamona (Híbrido 12 e Híbrido 18) foram cultivados em duas formas de condução: (i) plantas sem nenhuma limitação ao crescimento e (ii) plantas com limitação do crescimento secundário do caule (poda e desbaste). A limitação do crescimento secundário das plantas resultou em maior partição de assimilados para o racemo primário das plantas, promovendo maior número e massa de grãos. Como resultado, plantas com apenas o racemo primário apresentaram produtividade de grãos equivalente a plantas que cresceram sem limitações. A produtividade de óleo em plantas com apenas o racemo primário foi equivalente a plantas testemunha para o Híbrido 12 e superiores para o Híbrido 18, com a vantagem da obtenção de plantas com maturação uniforme.

Palavras-chave: *Ricinus cummunis* L; fonte-dreno; manejo de plantas.

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INTRODUCTION

Castor bean (*Ricinus communis* L) is an important crop of industrial interest, with oil characteristics allowing multiple application, from medicinal products to aviation fuel, additives, lubricants, and biodiesel (Ogunniyi, 2006; Hall *et al.*, 2009). The main competitive advantage of castor bean oil is the presence of large amounts of ricinoleic acid, which grants potential features for the oil (O'Brien, 2000). Great part of global castor production is in India, China, and Brazil, with plants grown in small fields where harvest is still predominantly manual due to the growth pattern of the plants (Severino *et al.*, 2012).

Castor bean plant has indeterminate growth habit with continuous and sequential flowering and fruiting during its cycle. When water and nutrients are available, the plant grows continuously in a sympodial pattern, which is a characteristic of this type of plant (Savy Filho, 2005). The growth habit of castor bean plants has a direct effect on fruit maturation, which is not uniform because, while the fruits of the primary racemes are mature, fruits of other racemes are still in development (Moshkin, 1986).

The growth habit of the plant also promotes a remarkable competition between sinks due to the flowering of the primary raceme, which competes in assimilate with secondary stems in early development, notably reducing its yield potential (Fioreze *et al.*, 2016). Thus, manipulation of castor bean growth development to provide development of only one raceme per plant may promote high yield with shortened cycle and uniform maturity, which are considered key characteristics for crop success worldwide (Severino *et al*., 2012).

Progress has been achieved with respect to plant height, architecture, and cycle length of castor bean plants as results of breeding programs (Severino *et al.*, 2012), which greatly increases the expectation for the development of more productive and efficient plants, as occurred to a variety of cultivated species. The development of plant ideotypes by cultivation practices or breeding should include a meticulous study of interrelations between plant growth, its physiological aspects, and the definition of crop yield components. Therefore, this study aimed to verify the effect of limiting the plant secondary growth on growth and yield parameters of castor bean plants.

MATERIAL AND METHODS

The experiment was conducted at the experimental farm of College of Agricultural Sciences, Sao Paulo State University (UNESP) in Botucatu, São Paulo, Brazil, under geographic coordinates of 22° 49' 31" S, 48° 25' 37" W, and 750 m altitude. Plants were cultivated as off-season between February and May 2012, in an Clayey Alisol (IUSS, 2015). Soil characteristics at planting were: clay = 420.0 g kg^{-1}; organic matter = 21.0 g dm^{-3}; pH ($CaCl_2$) = 5.8; Ca, Mg, K, and Al = 53.0, 28.0, 2.7, and 1.0 $cmol_c$ dm^{-3}, respectively; P_{resin} = 33.0 mg dm^{-3}; and base saturation = 74%.

The experimental design was a randomized block design in a factorial 2 × 2, with four replications. Two castor bean hybrids (Hybrid 12 and Hybrid 18) developed by the breeding program for non-edible oilseed species of FCA/UNESP were utilized for this experiment. Plants were cultivated in two manners: (i) plants without growth limitation (control), and (ii) plants subjected to secondary growth limitation (thinning with pruning). Each experimental unit was composed of five 15-m rows at a 0.4-m inter-row spacing. The two middle rows (54 plants) were considered as harvest rows, discarding plants of the edges. Seeds were sown to obtain 48,000 uniform plants ha^{-1}.

The experiment was carried out under no-tillage system with soybean as preceding crop. The experimental site had an irrigation system available, which was used for surface application of 450 mm water after sowing as well as in low precipitation periods. Base fertilization was mechanically performed in the rows with application of 300 kg ha^{-1} formulated fertilizer (04-14-08). Sowing was manually performed in February 2012 with three seeds per hole. The seeds were treated with fungicide and insecticide (Carboxin-Thiram + Tiametoxan, respectively). After emergence, thinning was done to maintain one plant per hole. Manual weeding was performed at 20 and 50 days after emergence (DAE) for weed control. At 20 DAE, 30 kg ha^{-1} K_2O (potassium chloride as source) and 40 kg ha^{-1} N (urea as source) were sidedress applied.

The occurrence of the primary raceme of castor bean plants was observed at 35 DAE for Hybrid 12 and 40 DAE for Hybrid 18. After onset of the primary raceme development, castor bean plants present a natural break in apical dominance, resulting in appearance of lateral stems. At this stage, all secondary stem primordia were removed (thinning with pruning treatment), including productive stems and stem buds from the base of primary stem (Figure 2). The removal of stem primordia was performed manually with tweezers. For the remaining plants (control treatment), all secondary stems were maintained.

Measurements were performed at 70, 90, 110, 130, and 150 days after emergence, with each experimental unit being divided into five equal portions composed of six conducive plants in each portion. For each time point, plant height and number of leaves per plant were evaluated. The biometric characteristics evaluated in the laboratory were leaf area, stem dry matter, and rachis length and diameter. Then, yield components (number of fruits and grains per raceme, grain dry weight per raceme, and hundred grains dry weight), grain yield, seed oil content, and seed oil yield were determined. The oil content was evaluated using samples of approximately 10 g seeds per plot by Nuclear

Magnetic Resonance method at the laboratory of Brazilian Agricultural Research Corporation, in Sao Carlos, SP, Brazil.

Data were subjected to analysis of variance by F test ($p < 0.05$) and the means were compared using Student's t test ($p < 0.05$).

RESULTS

Average daily temperature and precipitation during the experimental period are presented in Figure 1. Average minimum and maximum temperatures were 17.5 °C and 28.8 °C, respectively, and average relative humidity was 77.1%. Cumulative precipitation during the experiment period was 550 mm.

Interaction was observed between cultivation systems and hybrids for oil yield. For the other variables, only differences in plant cultivation systems were observed.

The removal of secondary stem primordia promoted significant reduction in plant height at 110 DAE (Figure 3a). At 150 DAE, plants with only the primary raceme showed height 40 cm lower than the control. As a result of the secondary stem removal, castor bean plants presented reduction in stem dry matter in relation to the control (Figure 3b). In both treatments, there was a reduction in accumulated dry matter of these tissues at the end of the period due to a mobilization of stem reserve to grains at the end of grain filling stage.

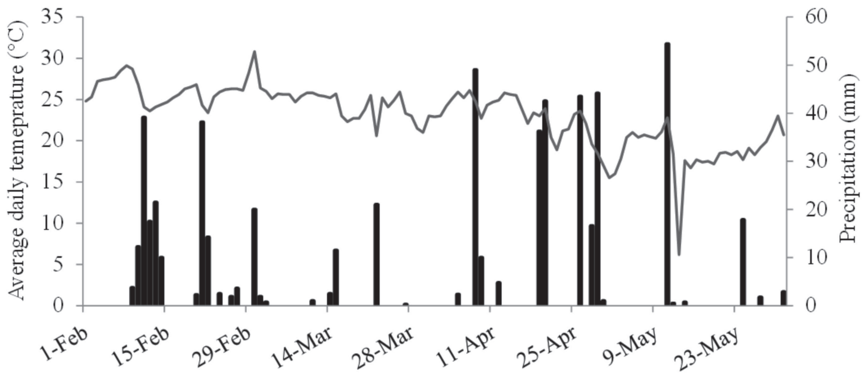

Figure 1: Average daily temperature (–) and Precipitation (**I**) between February and May, 2012 in Botucatu, SP, Brazil.

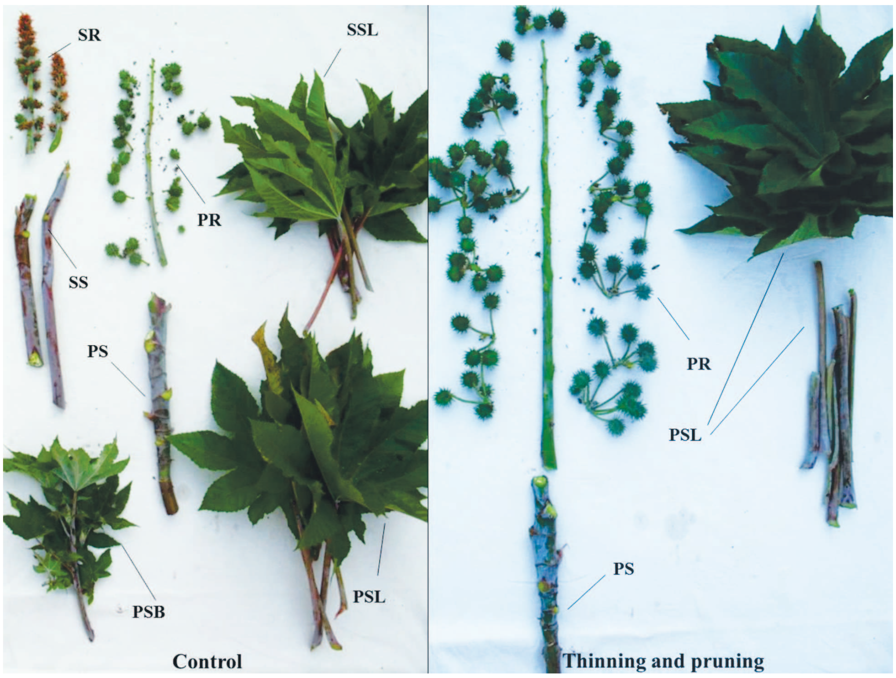

Figure 2: Vegetative and reproductive development of castor plant (Hybrid 18) as affected by thinning and pruning in Botucatu, SP, Brazil.

PS: primary stem; PSL: primary stem leaves; PR: primary raceme; SS: secondary stems; SSL: secondary stem leaves; SR: secondary racemes; PSB: primary stem buds.

The removal of the secondary growth reduced the number of leaves, with higher number of leaves at 70 DAE, and then plants being completely leafless at 150 DAE (Figure 3c). Control plants presented higher number of leaves at all times, increasing number of leaves up to 90 DAE, followed by a decrease at the end of the experimental period, although defoliation was not complete. For leaf area, plants showed the same response of number of leaves, except at 70 DAE (Figure 3d).

The change in the source-sink relation promoted by the treatments reflected in the growth and development of primary racemes of castor bean plants (Figure 4). Plants with only primary growth produced larger racemes, in diameter (Figure 4a) and length (Figure 4b), which were also more productive with the increase in number of fruits (Figure 4c) and seeds (Figure 4d).

Higher number of seeds at the primary raceme of castor bean plants influenced grain dry matter per raceme at 110 DAE (Figure 5a). Plants that had the secondary stem removed presented significantly higher grain dry matter per raceme than the control, mainly at the end of the cycle (150 DAE). This response is due to higher number of fruits and seeds per raceme (Figures 4b and 4c), as hundred grains dry weight was not affected by the treatments (Figure 5b).

Considering only the primary raceme, castor bean plants that had the secondary growth primordium removed were more productive than the control (Figure 6a), exceeding 3000 kg ha^{-1} grains in only one raceme. Oil content was lower than the control (Figure 6b); however, plants with limitation in secondary growth presented higher oil yield (Figure 6d), considering harvest of only the primary raceme. It was observed that the highest accumulation rate of oil in castor bean seeds occurred between 90 and 130 DAE. This period refers to 70 and 90 days after raceme appearance for Hybrid 12 and 75 and 95 days for Hybrid 18. This response did not follow the same pattern for total dry matter accumulation in grains (Figure 5a).

Differences in final grain yield was not observed when comparing plants with one raceme with control plants (Fi-

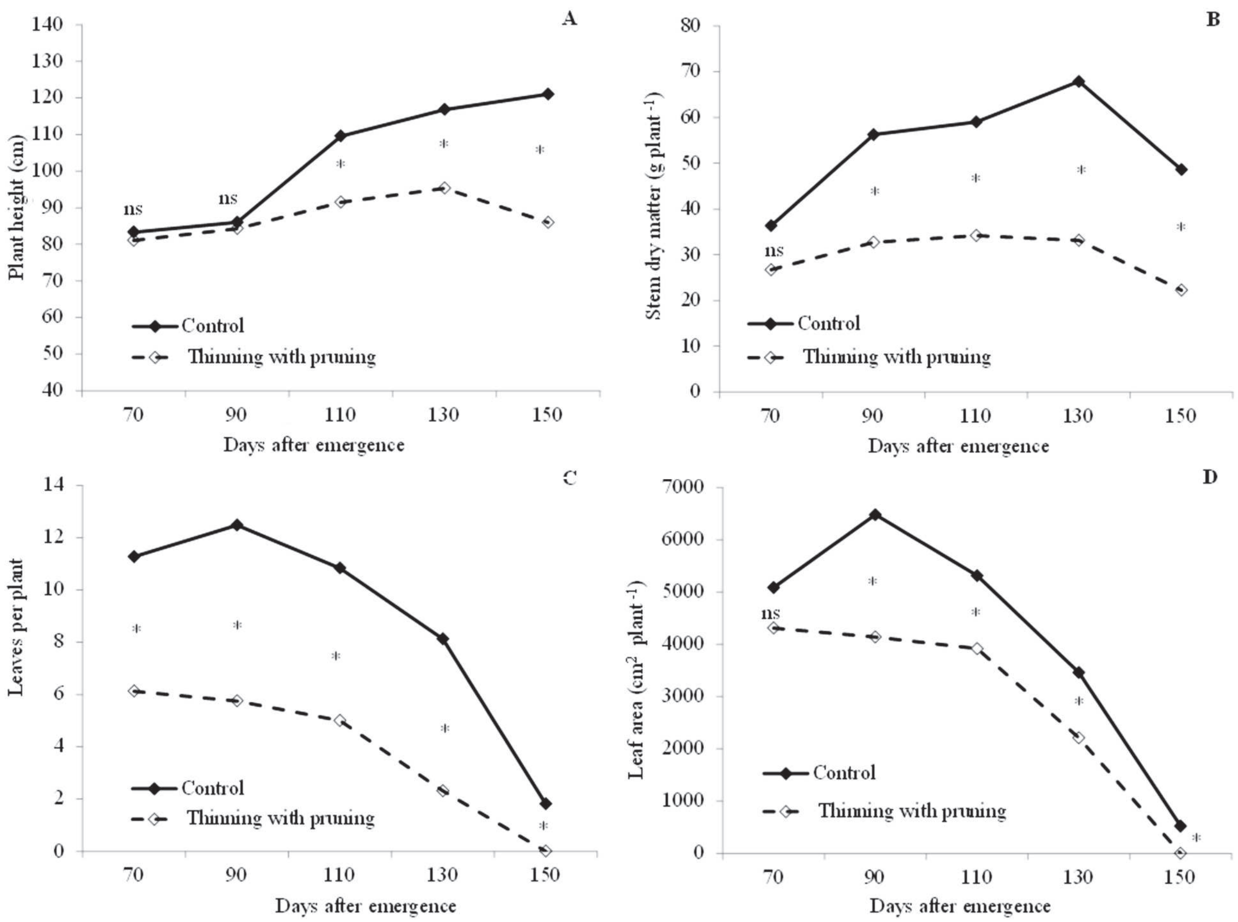

Figure 3: Castor bean plant height (A), stem dry matter (B), number of leaves (C), and leaf area (D) per plant, as affected by thinning and pruning in Botucatu, SP, Brazil.

Each point is an average across the hybrids 12 and 18.

(*) and (ns) denote signiûcant (p = 0.05) and non-significant difference, respectively, according to LSD test.

gure 6b), indicating that the primary raceme of plants that had the secondary stem removed produced an equivalent amount of grains as the control plant, which had a primary raceme and two secondary racemes.

Hybrid 12 showed higher oil yield than Hybrid 18 for plants with secondary growth limitation (Table 1). In contrast, Hybrid 18 produced approximately 1000 kg more oil than Hybrid 12 when secondary stems were removed.

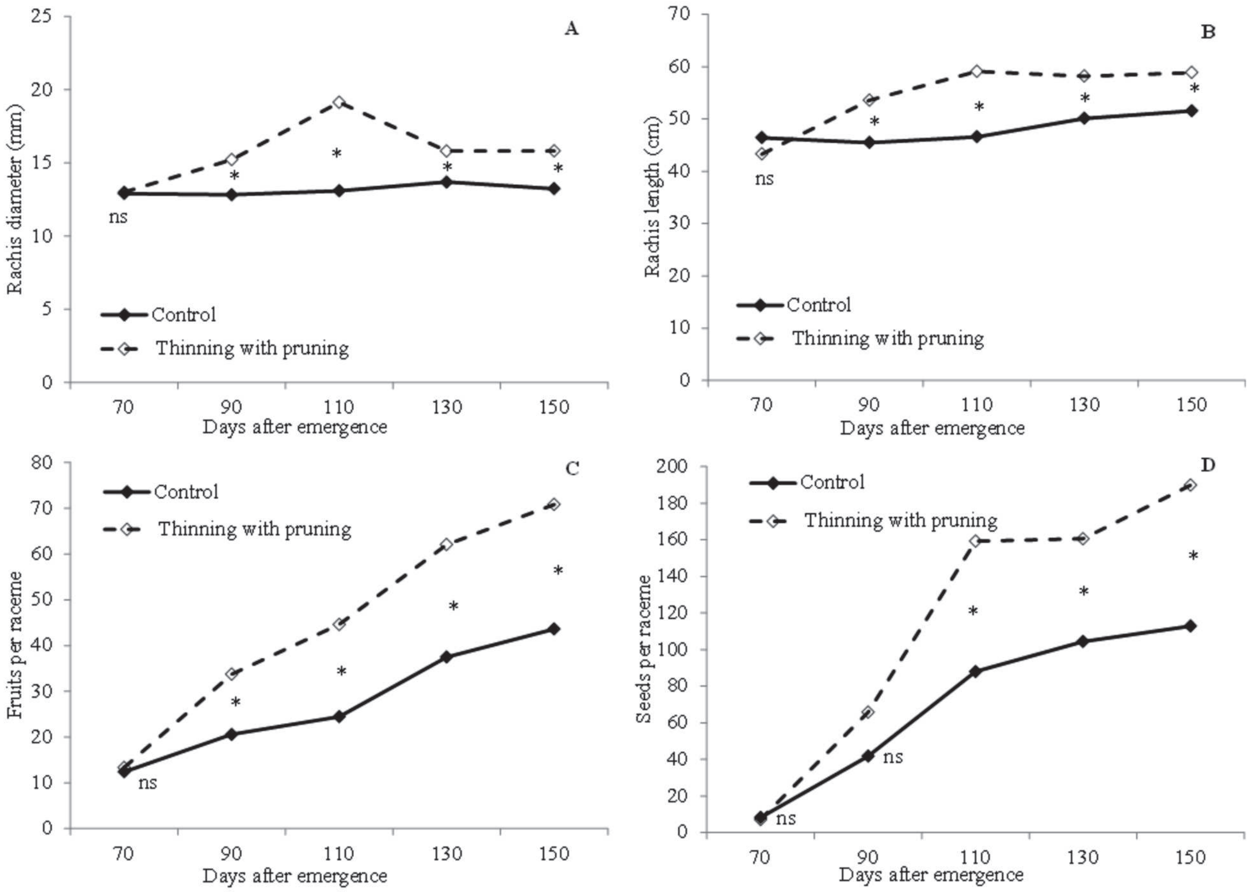

Figure 4: Rachis diameter (A) and length (B), and number of fruits (C) and seeds (D) at the primary raceme of castor bean plants as affected by thinning and pruning in Botucatu, SP, Brazil.

Each point is an average across the hybrids 12 and 18.
(*) and (ns) denote signiûcant (p = 0.05) and non-significant difference, respectively, according to LSD test.

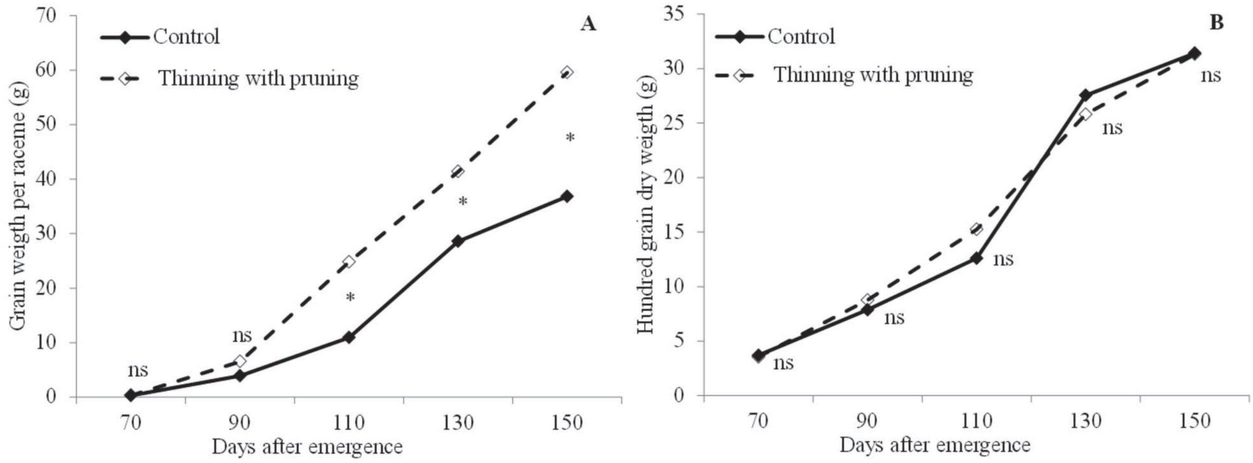

Figure 5: Grain weight per raceme (A) and hundred grain dry weight (B) of castor bean plants, as affected by thinning and pruning in Botucatu, SP, Brazil.

Each point is an average across the 12 and 18 hybrids. (*) and (ns) denote signiûcant (p = 0.05) and non-significant difference, respectively, according to LSD test.

Oil yield of Hybrid 12 was not affected by secondary stem removal. Hybrid 18 showed higher oil yield when cultivated with only one primary raceme. The two hybrids responded differently regarding the cultivation methods, suggesting that genetic variability exists as a response of management of racemes.

DISCUSSION

The primary raceme of plants with secondary stems removed presented higher production than primary and secondary racemes of the control. These results are in accordance with Diniz *et al.* (2009a, b), for cultivar BRS 188 Paraguaçu, and Fioreze *et al.* (2016), for cultivar IAC 2028. Castor bean plants present evident competition among sinks after onset of reproductive development. Right after appearance, primary raceme competes for assimilates and nutrients with at least two secondary stems in early vegetative development until secondary stems develop their own photosynthetic apparatus.

Removal of secondary stems at bud stage directs available assimilates to a single sink, the primary raceme. We speculate that the higher number of female flowers (which results in higher fruit number) grown in plants with secondary racemes removed might be due to an increase in availability of assimilates and nutrients, as well as hormonal alteration promoted by bud removal. Similar behavior was observed by Diniz *et al*. (2009a) and Fioreze *et al*. (2016). In Figure 2, differences in growth pattern of

Table 1: Total oil yield of two castor bean hybrids at 150 days after emergence as affected by thinning and pruning in Botucatu, SP, Brazil

Total oil yield (kg ha^{-1})		
	Hybrid 12	**Hybrid 18**
Control	1980,8 Aa	1019,7 Bb
Thinning with pruning	1345,7 Ba	2333,0 Aa

Uppercase letters refer to hybrids, lowercase letters compare thinning and pruning of plants (LSD test; $p < 0.05$).

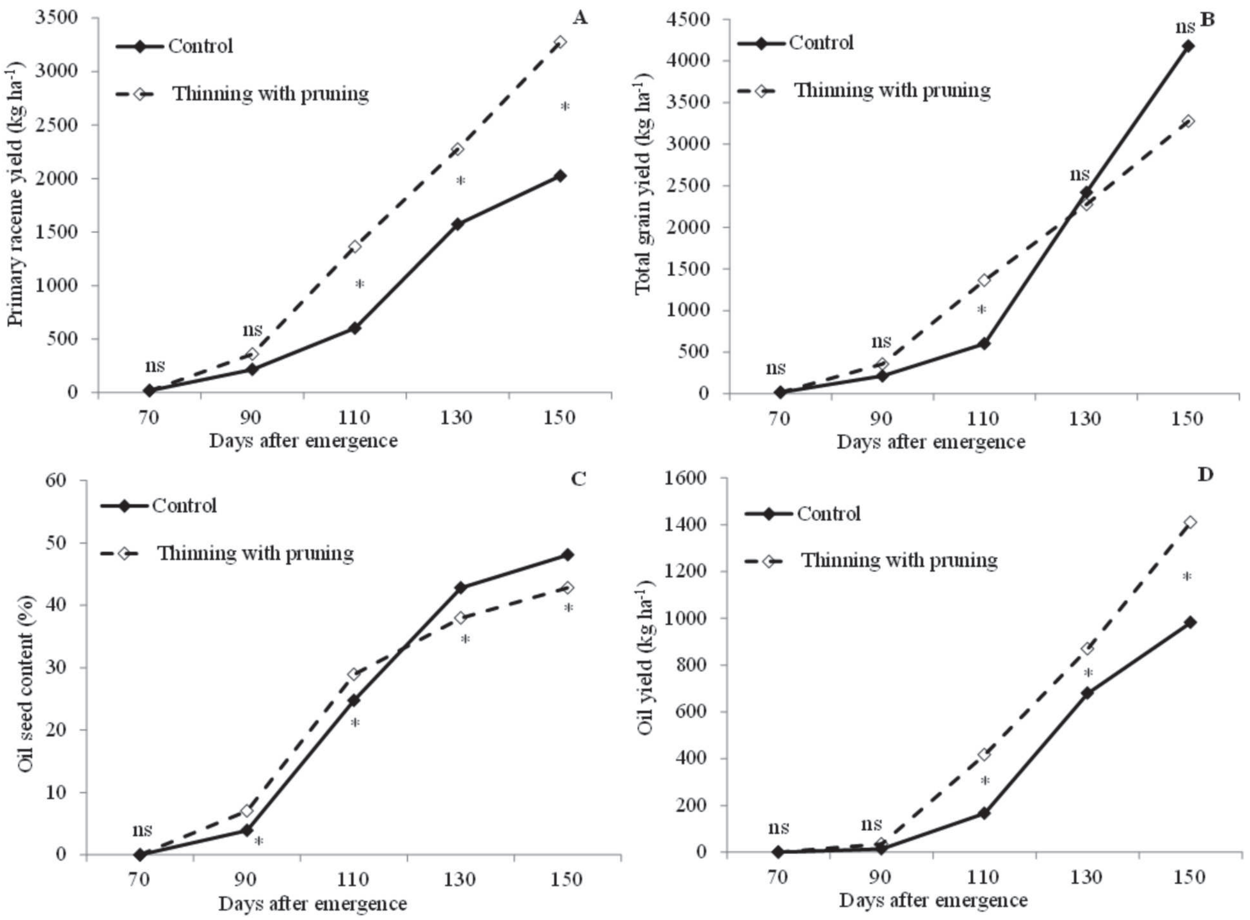

Figure 6: Primary raceme grain yield (A), total grain yield (B), oil seed content (C), and oil yield (D) of castor bean plants, as affected by thinning and pruning in Botucatu, SP, Brazil.

Each point is an average across the 12 and 18 hybrids.

(*) and (ns) denote signiûcant (p = 0.05) and non-significant difference, respectively, according to LSD test.

plants with and without limitation of secondary growth can be observed, as well as the effects of assimilates directed to reproductive structures in plants with secondary stem removal.

The higher number of seeds in racemes of plants subjected to removal of secondary stems did not affect filling ability, as hundred grains dry weight was not affected in any of the measurements. The loss of leaf area promoted by the removal of secondary stems reduces potential surface area for photosynthesis. On the other hand, lower leaf area reduces shading of leaves inserted in the first portion of the stem, extending their life cycle, thus maximizing grain filling of fruits of primary raceme. Early senescence of leaves from the first portion of the stem, when secondary stems are in development, is common in castor bean plants. In this case, leaf abscission might occur due to shading (Lim *et al.*, 2007). The period prior to foliar senescence in castor bean is marked by translocation of assimilates and nitrogen compounds from the leaves to other plant tissues (Jongebloed *et al.*, 2004).

In this study, the total leaf loss of the first portion of stems from plants that had secondary raceme primordia removed was observed only at 150 DAE (Figures 3c and 3d), supporting the hypothesis that shading promoted by secondary stems is a determining factor for leaf abscission in primary stems. Another hypothesis to consider is that leaf life cycle is controlled by the grain filling process in the raceme of the stem where the leaves are inserted (controlled by sink strength). In this research, it was observed that primary raceme of control plants started maturation while secondary racemes were still maturing (data not presented), coinciding with leaf abscission at the first portion of the stem. In plants that had their secondary stems removed, grain filling of primary raceme was extended until 150 DAE (Figure 5a), whereas the leaves remained green until at least 130 DAE (Figure 3d).

The relation between number of leaves and racemes is maintained when secondary stems are removed, as each stem has its leaves responsible for the development of the inserted racemes under non-limiting growth conditions. Thus, it is evident that leaves from first portion of racemes are able to support development of greater amount of fruits and seeds, provided that there is no competition among sinks or shading. This result contrasts that of Severino & Auld (2013), who hypothesized that the increase in number of female flowers, which would increase sink strength, does not result in higher grain yield of castor bean crop. The authors also suggested that the number of fruits of a raceme cannot be increased after the onset of raceme development. Another hypothesis to explain the observed results would be the reduction in flower abortion; however, Severino (2012) did not observe this reduction in flower abortion with a simulated sink reduction experiment. Our results, however, indicate that there may be a compensatory mechanism to increase flower occurrence and fruit set.

Considering that the final stage of grain development may coincide with occurrence of water scarcity or low temperatures, depending on the growth location, growth pattern and plant cycle shortening are crucial for maintaining crop yield (Severino *et al.*, 2012). Additionally, other risk factors for castor bean crop can be minimized, such as gray mold (*Amphobotrys ricini*), as the removal of secondary stems results in higher incidence of direct light and airflow on the plant, promoting a microclimate less beneficial to fungal growth (Sussel *et al.*, 2011).

Oil content was negatively affected by the secondary growth limitation of castor bean plants. This response is likely due to the higher amount of leaves as well as the period of green foliar area in the control plants, considering that the oil is one of the last components accumulated during grain development (Moshkin, 1986). Severino *et al.* (2010) observed linear reduction in seed oil content of castor bean for defoliation levels between 15 and 60%.

The results of this research demonstrate that the change in source-sink relation promoted by removal of secondary growth primordia of castor bean results in an increase of growth and production of primary raceme. However, plants with this characteristic are as a challenge to be reached by studies on new agricultural practices or development of new genetic materials. Regarding breeding, advances have been made with respect to plant height and architecture by incorporating low height, short petiole, and reduced cycle characteristics into the plants (Severino *et al.*, 2012). Castor bean genotypes with low tendencies to branch have been selected using the pedigree method (Baldanzi & Pugliesi, 1998), but there is not a mutant in castor bean with a non-branching habit (Baldanzi *et al.*, 2003). Previous breeding programs seem to be insufficient to induce or find such a mutant. Alternatively, since ancestral body plan traits are maintained due to the presence of pivotal developmental processes (e.g., branching), whose modification would be difficult (Niklas, 2000), this mutation might not appear in a perennial species such as castor bean.

A future possibility on the development of management techniques to alter growth pattern of castor bean plants exists. Limitation of plant growth with management practices is frequent and has positive results in the source-sink relations of several crops, such as tomato and watermelon. This type of management, however, is performed in small sites and is highly dependent of human labor, since it is a manual management. For seed production, this technique might be viable as there are plants with transitional forms of sexual expression (Popova & Moshkin, 1986). One of them is called unstable female, which primary raceme is 100% female and the racemes of lateral stems are partially or completely monoecious. Therefore, it is possible to use this management for inclusion of female lines in the production of hybrid seeds. In addition to ensure genetic purity, this would shorten production cycle, reducing costs associated with irrigation and human labor for removal of male flowers in racemes of lateral stems.

In tobacco plants, inhibition of lateral bud appearance is performed chemically by using “bud suppressing” products, such as Flumetralin. Growth regulators are successfully used to balance vegetative and reproductive growth in cotton plants (Reddy *et al.*, 1996; Wang *et al*., 2014). These products seem to have little or no effect on secondary growth of castor bean plants, as indicated by Oswalt *et al.* (2014). The study of new formulations, or even an adaptation of products already being used successfully in other crops, is crucial for knowledge advance in the area. It is known, however, that the success of this type of management depends on meticulous studies of concentration and time of application of these products.

CONCLUSIONS

The removal of secondary stem results in an increased yield of the primary raceme of castor bean plants by increasing grain number and grain dry weight of racemes;

Grain yield in plants with only the primary raceme is equivalent to plants with primary and secondary growth in both tested hybrids;

Oil yield in plants with only the primary raceme is equivalent to plants with secondary growth for Hybrid 12 and higher for Hybrid 18.

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