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# Does a high sowing density of common bean change the weed interference periods?

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**ABSTRACT:** In order to determine the effect of sowing density on weed interference in common bean, two experiments were carried out in Jaboticabal municipality in 2020: one with 15 (FPM) and other with 10 bean plants $m^{-1}$ (TPM). The treatments were periods of control and coexistence: 0-10, 0-20, 0-30, 0-40, 0-50, 0-60, and 0-80 days after emergence (DAE), totaling 14 treatments, in four replications, under a randomized block design. Was carried out a phytosociological analysis of the weeds and the regression of their dry mass with productivity. Nonlinear regression analysis of productivity was performed to determine the period before interference (PBI), critical period for interference prevention (CPIP) and total period interference prevention (TPIP). The predominant species were: *Nicandra physaloides*, *Digitaria nuda*, and *Brachiaria plantaginea*. CPIP in FPM showed a reduction in four days and PBI had an increase of 7 DAE, compared to TPM. The accumulation of weed dry mass exponentially decreased crop productivity, this decrease being greater in FPM compared to TPM. The higher sowing density gave the culture greater competitive capacity over some weed species.

**Key words:** cultural weed control; *Phaseolus vulgaris* L.; plant density

# A alta densidade de semeadura do feijoeiro-comum altera os períodos de interferência das plantas daninhas?

**RESUMO:** Com o objetivo de determinar o efeito da densidade de semeadura na interferência das plantas daninhas em feijoeiro-comum, foi conduzido no município de Jaboticabal em 2020 um experimento com 15 (QPM) e outro com 10 plantas de feijoeiro $m^{-1}$ (DPM). Os tratamentos foram os períodos de controle e convivência: 0-10, 0-20, 0-30, 0-40, 0-50, 0-60 e 0-80 dias após a emergência (DAE), em quatro repetições e sob o delineamento de blocos casualizados. Realizou-se a análise fitossociológica das plantas daninhas e a interação da sua massa seca com a produtividade do feijoeiro. A análise de regressão não linear da produtividade foi feita para determinar o período anterior à interferência (PAI), período crítico de prevenção à interferência (PCPI) e período total de prevenção à interferência (PTPI). As espécies predominantes foram: *Nicandra physaloides*, *Digitaria nuda* e *Brachiaria plantaginea*. O PCPI em QPM mostrou redução em quatro dias e o PAI aumentou em 7 DAE, em comparação com DPM. O acúmulo de massa seca das plantas daninhas diminuiu exponencialmente a produtividade da cultura. A maior densidade de semeadura conferiu à cultura maior capacidade competitiva sobre algumas espécies plantas daninhas.

**Palavras-chave:** controle cultural de plantas daninhas; *Phaseolus vulgaris* L.; estande de plantas

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## Introduction

The bean crop occupies a significant place in world nutrition due to its high protein, calcium, iron, zinc, vitamins, fiber, antioxidants, and polyphenols content (Karavidas et al., 2022), constituting an ally in the fight against malnutrition. FAOSTAT (2022) put Brazil in third place in world production of dry-grain beans, after India and Myanmar, with a volume of 3,035,290 ton in the year 2020. Data from CONAB (2022) indicate that, despite the impact of the Covid-19 pandemic, Brazilian bean production in the 2021/2022 crop was 6.7% higher than in the 2020/2021 crop.

The optimum productivity of the bean plant depends on both climatic factors and agronomic management, especially weed control. Considering that the crop has low competitive ability, weed interference can reduce yield by 80.4% due to decreased stand and number of pods per plant (Schiessel et al., 2019). In addition, the 71% productivity loss is valued at $622 million in the United States and $100 million in Canada, according to Soltani et al. (2018).

The periods in which the crop may suffer losses in productivity as a result of living with the weed community are called interference periods and are usually expressed in days after emergence or sowing. Amaral et al. (2019) used three interference periods: period before interference or PBI (period when weeds can coexist with the crop without significant reduction in productivity), total period interference prevention or TPIP (period after emergence when the crop must be kept free of the weed community so that its yield or other characteristics are not significantly altered), and critical period for weed control or CPIP (period when weed control is required).

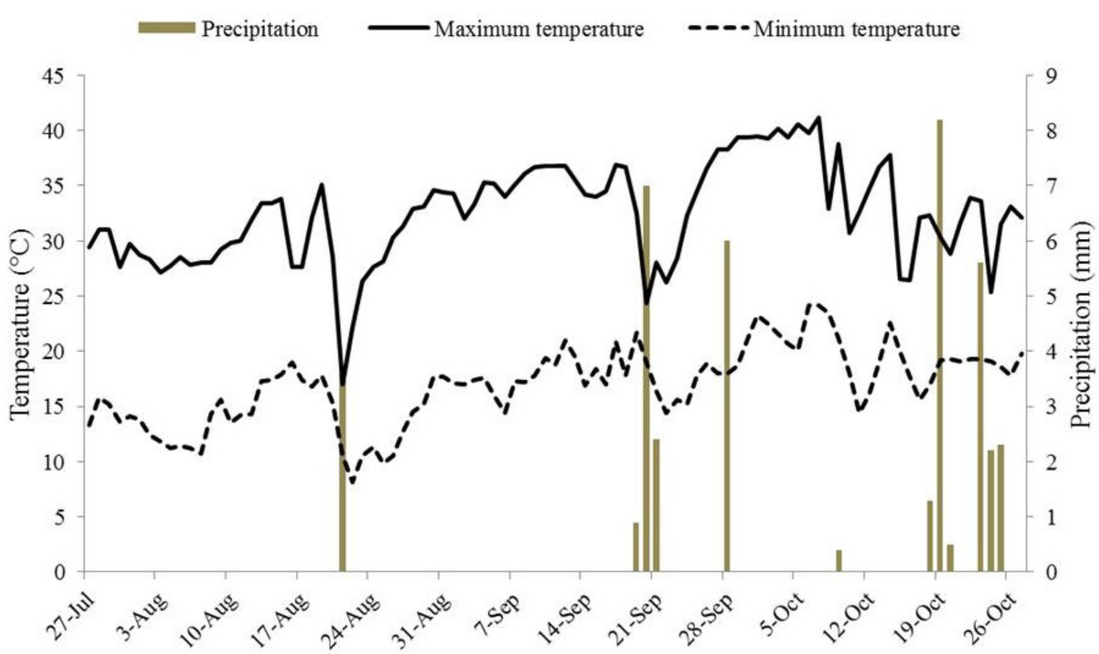
High sowing density of bean can favor early ground cover and competitive ability with weeds (Musana et al., 2020), consequently the duration of interference periods can be altered. Scholten et al. (2011) found that the highest PBI was at a spacing of 0.45 m and a sowing density of 15 plants m$^{-1}$, when compared to a spacing of 0.60 m and a density of 10 plants m$^{-1}$ of common bean. Coincidentally, Parreira et al. (2012) detected a four-day increase in PBI at a density of 15 plants m$^{-1}$ and spacing of 0.45 m, compared to PBI obtained at a density of 10 plants m$^{-1}$ and spacing of 0.60 m for common bean.

Considering the control of weeds and the influence of sowing density in the periods of significant interference in the agronomic management of the bean, works of this nature can make the management of the weed community more rigorous and efficient, saving time and resources. Therefore, the objectives of the present study were to determine the effect of two sowing densities of the bean plant on weed interference periods, as well as to characterize the weed community coexisting with the crop and correlate it with its interference on crop productivity.

## Materials and Methods

Two experiments (10 and 15 plants m$^{-1}$) were conducted in the field at the experimental area of the Universidade Estadual Paulista, Jaboticabal, São Paulo, Brazil (21° 15’ 17” S, 48° 19’ 20” W, and 590 m of altitude), from July to October 2020. The soil was classified as ‘Latossolo Vermelho Eutroférico’ with a clayey texture (total sand = 210 g kg$^{-1}$, silt = 390 g kg$^{-1}$, clay = 400 g kg$^{-1}$), pH($CaCl_2$) = 5.4, organic matter = 17 g dm$^{-3}$, P (resin) = 16 mg dm$^{-3}$, K = 0.6 mmol$_c$ dm$^{-3}$, Ca = 20 mmol$_c$ dm$^{-3}$, Mg = 9 mmol$_c$ dm$^{-3}$, and H + Al = 27 mmol$_c$ dm$^{-3}$.

The region climate is Cwa with summer rainfall and a relatively dry winter, according to the Köppen classification. The climatic data are presented in Figure 1.




Source: Agroclimatological Station - Department of Exact Sciences, FCAV/UNESP - Jaboticabal Campus, São Paulo, Brazil.

**Figure 1.** Climatic conditions during the experiment in 2020.

The soil was prepared conventionally by scarifying, plowing, and harrowing. The bean cultivar was TAA Dama, which has type III indeterminate growth habit. Sowing was on July 27, 2020 at a density of 18.5 seeds $m^{-1}$ and spacing of 0.45 m between rows, leaving 10 plants $m^{-1}$ in the TPM experiment and 15 plants $m^{-1}$ in the FPM experiment after thinning. The first fertilization was at sowing with 200 kg $ha^{-1}$ of the formulated 8-28-16 of N, P, and K, and the second was at the V4 phenological stage (third trifoliolate leaf open), applying 144 kg $ha^{-1}$ of nitrogen in cover. In addition, preventive and curative applications of defensives were made to control pests and diseases.

The experimental design was a randomized block design with 14 treatments in four replicates for both the TPM and FPM experiments. The experimental unit was a five-row, 5-m-long plot, with one row on each side and 1-m on the extremities as a border, leaving 4.05 $m^{-2}$ of usable area. The treatments consisted of the increasing control periods 10, 20, 30, 40, 50, 60, and 80 days after emergence (DAE), after these periods the weeds were not controlled until the end of the cycle. In the coexistence periods, the weed community was maintained for the same periods, and manual weeding was performed after each coexistence period and until the end of the crop cycle.

The harvest was semi-mechanized, on October 26, 2020, by letting the plants dry until the grains reached the appropriate moisture for mechanical threshing. The moisture of the grains was measured with a MTG-640® portable determiner and then they were weighed on precision scales to calculate yields, correcting the weight to 13% moisture and the results extrapolated to kg $ha^{-1}$.

Weed assessments were conducted at the end of each period in the treatments with coexistence and at harvest in the treatments with control, using a 50 cm square frame, dropped twice in the central rows of each treatment. The weeds within the frame were identified, counted, and taken to the forced circulation oven for 72 hours at 70 °C until they reached constant weight. The results were used to calculate phytosociological parameters, according to Equations 1 to 6 (Mueller-Dombois & Ellenberg, 1974):

$$\text{Absolute frequency} = \left(\frac{\text{NSi}}{\text{NSt}}\right)\times 100 \tag{1}$$

$$\text{Relative frequency}(\text{RF}) = \left(\frac{\text{Fri}}{\sum \text{Fri}}\right)\times 100 \tag{2}$$

$$\text{Relative density}(\text{RD}) = \left(\frac{\text{Ni}}{\text{Nt}}\right)\times 100 \tag{3}$$

$$\text{Relative dominance}(\text{ReD}) = \left(\frac{\text{Dmi}}{\sum \text{Dmi}}\right)\times 100 \tag{4}$$

$$\text{Importance value index} = (\text{RF}+\text{RD}+\text{ReD}) \tag{5}$$

$$\text{Relative importance of each species} = \left(\frac{\text{IIVi}}{\sum \text{IIVi}}\right)\times 100 \tag{6}$$

where: NSi - number of samples in which the species i occurs; NSt - total number of samples taken; Fri - frequency of a given population; Ni - number of individuals of a species; Nt - total number of individuals of the weed community; Dmi - dry mass of a given population; and, IIVi - index of the importance value of a species.

The yield data were analyzed for each seeding density, and the results were subjected to non-linear regression analysis using Boltzmann sigmoidal model (Equation 7):

$$Y = \frac{(A1 - A2)}{1 + e^{(X - X_0)/dx}} + A2 \tag{7}$$

where: Y - grain yield in kg $ha^{-1}$; A1 - maximum yield in the treatments with control during the cycle; A2 - minimum productivity in treatments without control during the cycle; X - upper limit of the coexistence or control period in days; $X_0$ - upper limit of the coexistence or control period, corresponding to the middle value between the maximum and minimum productivity; and, dx - speed of yield loss or gain as a function of coexistence or control period.

Based on the regression equations of the sigmoidal model, the interference periods were determined, considering an arbitrary loss of 5% of the yield, comparing the treatment with the control throughout the cycle. In addition, correlation analyses of yield with weed dry mass (total and main species) were performed in increasing periods of coexistence. All analyses were performed with the help of OriginPro® software.

## Results

### Weed community composition

The number of species in the experiment at density 10 (TPM) and 15 plants $m^{-1}$ (FPM) was 17 and 19, respectively, with species being common at both densities: *Acanthospermum hispidum*, *Euploca procumbens*, *Raphanus raphanistrum*, *Senna obtusifolia*, *Sida rhombifolia*, *Portulaca oleracea*, *Richardia brasiliensis*, *Nicandra physaloides*, *Commelina benghalensis*, *Cyperus rotundus*, *Brachiaria plantaginea*, *Cenchrus echinatus*, *Digitaria nuda*, and *Eleusine indica*, representing 39% of the total number of species in both experiments (Table 1). The family Poaceae contributed the highest percentage of species in both FPM (26.3%) and TPM (24%) density.

### Weed density in coexistence periods

In sowings of 10 and 15 plants $m^{-1}$, the number of weeds tended to decrease as the coexistence period increased (Figures 2A and 2B). In FPM (Figure 2A), the maximum weed

**Table 1.** Weed species at sowing density of common bean 15 (FPM) and 10 (TPM) plants m⁻¹.

| Family | Scientific name | Common name | FPM | TPM |
|---|---|---|---|---|
| | | Eudicotyledonous | | |
| Amaranthaceae | *Alternanthera tenella* Colla. | Apaga fogo | X | |
| Amaranthaceae | *Amaranthus retroflexus* L. | Caruru | X | |
| Asteraceae | *Acanthospermum hispidum* DC. | Carrapicho-de-carneiro | X | X |
| Asteraceae | *Blainvillea dichotoma* (Murray) Stewart | Erva palha | | X |
| Boraginaceae | *Euploca procumbens* (Mill.) Diane & Hilger | Borragem | X | X |
| Brassicaceae | *Coronopus didymus* (L.) Smith. | Mentruz | | X |
| Brassicaceae | *Raphanus raphanistrum* L. | Nabiça | X | X |
| Convolvulaceae | *Ipomoea quamoclit* L. | Corda de viola | | X |
| Convolvulaceae | *Ipomoea* sp. | Corda de viola | X | |
| Fabaceae | *Senna obtusifolia* (L.) H.S. Irwin e Barneby | Fedegoso | X | X |
| Malvaceae | *Sida rhombifolia* L. | Guanxuma | X | X |
| Portulacaceae | *Portulaca oleracea* L. | Beldroega | X | X |
| Rubiaceae | *Richardia brasiliensis* Gomes | Poaia | X | X |
| Solanaceae | *Nicandra physaloides* (L.) Gaertn. | Joá-de-capote | X | X |
| Solanaceae | *Solanum americanum* Mill. | Maria pretinha | X | |
| | | Monocotyledonous | | |
| Commelinaceae | *Commelina benghalensis* L. | Trapoeraba | X | X |
| Cyperaceae | *Cyperus rotundus* L. | Tiririca | X | X |
| Poaceae | *Brachiaria plantaginea* (Link) Hitch. | Capim-marmelada | X | X |
| Poaceae | *Cenchrus echinatus* L. | Capim-carrapicho | X | X |
| Poaceae | *Digitaria nuda* Schumach. | Capim-colchão | X | X |
| Poaceae | *Eleusine indica* (L.) Gaertn. | Capim-pé-de-galinha | X | X |
| Poaceae | *Panicum maximum* Jacq. | Capim-colonião | X | |

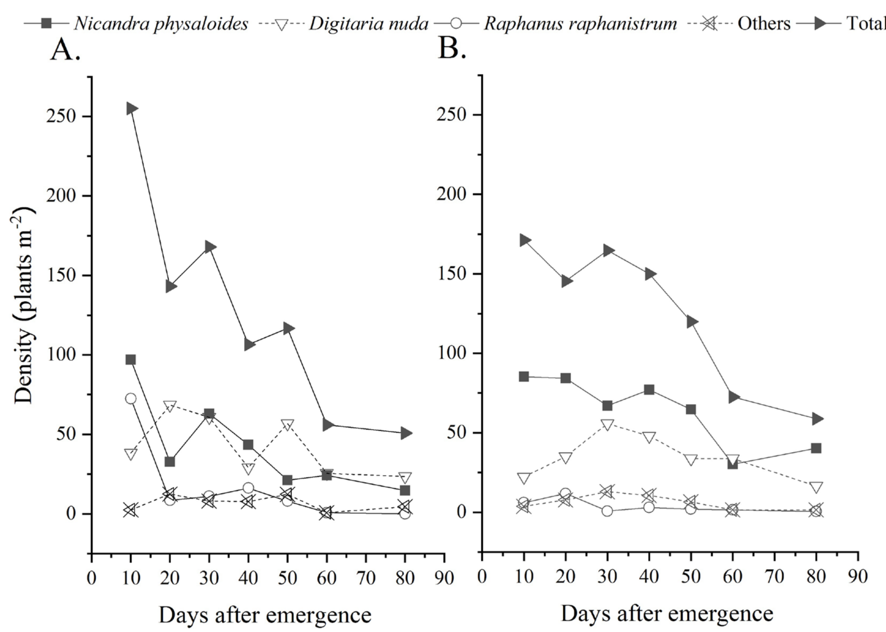



**Figure 2.** Weed density in the coexistence periods under sowing density of common bean of 15 (A) and 10 plants m⁻¹ (B).

density (250 plants m⁻²) occurred at 10 DAE with coexistence, presenting decreases and increases until 50 DAE; after this period, the density decreased until the final stage of the experiment. The species that had the highest density in the initial period were: *Nicandra physaloides* (100 plants m⁻²), *Raphanus raphanistrum* (75 plants m⁻²), and *Digitaria nuda* (38 plants m⁻²).

In the TPM experiment (Figure 2B), the maximum weed density (170 plants m⁻²) was recorded at 10 DAE, decreasing at 20 DAE and increasing at 30 DAE, then the density decreased until the end of the experiment. The species with the highest density in the initial period were: *Nicandra physaloides* (84 plants m⁻²), *Digitaria nuda* (20 plants m⁻²), and *Raphanus raphanistrum* (9 plants m⁻²). The average number of individuals per period for *Raphanus raphanistrum* and *Digitaria nuda* was higher in FPM, but *Nicandra physaloides* had lower average density in FPM compared to TPM.

### Dry mass of weeds in coexistence periods

The dry mass had an opposite behavior to the weed density, with increasing values of dry mass being observed as the coexistence periods increased (Figures 3A and 3B). The

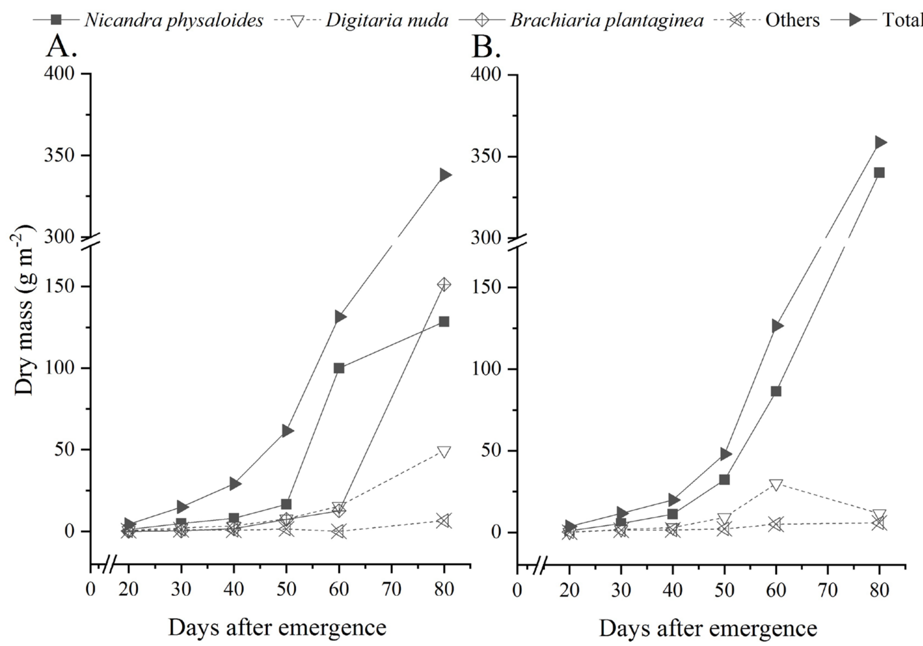



**Figure 3.** Dry mass of weeds in the coexistence periods under sowing density of common bean of 15 (A) and 10 plants m$^{-1}$ (B).

experiment with FPM density showed intense accumulation of weed community dry mass, with a maximum value (338.2 g m$^{-2}$) at 80 DAE (Figure 3A). *Nicandra physaloides* and *Brachiaria plantaginea* stood out as the species with the highest dry mass production throughout the experiment, with *Brachiaria plantaginea* presenting the highest value at 80 DAE (151.3 g m$^{-2}$), compared to the other species. Both weeds contributed 83% of the total dry mass at 80 DAE (Figure 3A).

In TPM, the highest value of weed dry mass (358.6 g m$^{-2}$) was at 80 DAE, and *Nicandra physaloides* with 340.1 g m$^{-2}$ was the main species that contributed to this value, showing higher values than in FPM, thus suppressing the other species in the TPM experiment (Figure 3B).

## Relative importance of weeds in coexistence periods

In FPM seeding, *Nicandra physaloides* showed the highest values of relative importance (RI) in the increasing periods with coexistence, except at 20 and 50 DAE, in which the greatest highlight was for *Digitaria nuda* (Figure 4A). Thus, the two species that maintained high RI values throughout the experiment. The only species that showed RI values with an upward trend was *Brachiaria plantaginea*, reaching third place (28%) at 80 DAE (Figure 4A).

In the TPM treatment group, *Nicandra physaloides* showed the highest RI values in all periods, with the maximum value (70%) at 80 DAE of coexistence (Figure 4B). The average RI of the same species was higher in TPM (44.4%) than in FPM (30.2%).

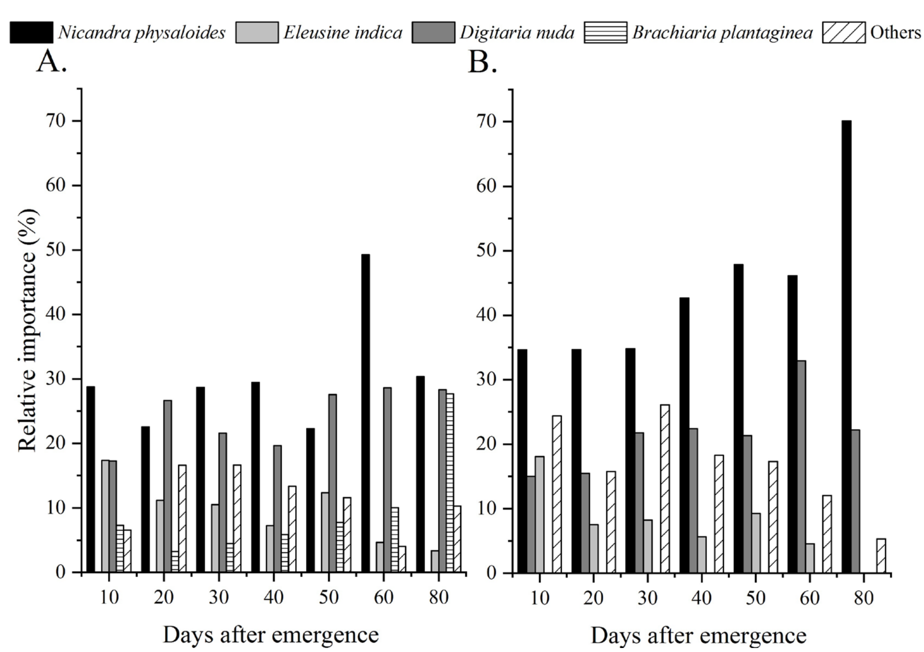



**Figure 4.** Relative importance of weeds in the coexistence periods under sowing density of common bean of 15 (A) and 10 plants m$^{-1}$ (B).

Another relevant species was *Digitaria nuda*, which starts to stand out as the second most important species starting at 40 DAE, showing the maximum RI value (33%) at 60 DAE (Figure 4B). However, the highest average RI of this species was in the FPM experiment (24.2%), compared to TPM (21.6%).

### Interference periods

Under the conditions of the experiment with FPM sowing density, the period in which the crop can coexist with the weeds (PBI) was 29 DAE, the total period interference prevention (TPIP) was 62 DAE, after which no weed community control was necessary. Thus, the critical period for weed control (CPIP) was from 29 to 62 DAE, making an interval of 34 days (Figure 5).

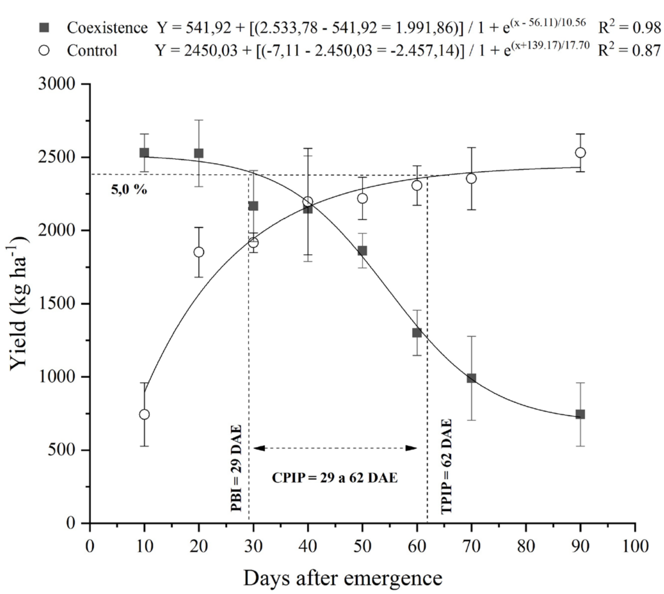
Regarding productivity in FPM, a loss of 70.6% in crop productivity can be observed when it lived the entire cycle with weeds (743.4 kg ha$^{-1}$) compared to the crop that had constant control of these plants (2,530.3 kg ha$^{-1}$) (Figure 5).

On the other hand, in the experiment with TPM density, it can be seen that the PBI was 22 DAE and the TPIP was 59 DAE. Consequently, the CPIP started at 22 DAE and extended until 59 DAE, defining a time interval equal to 38 days (Figure 6).

In the TPM density, there was a reduction of 70.3% in productivity in the bean treatment living with the weed community throughout the cycle (880.9 kg ha$^{-1}$) compared to the treatment always free of weeds (2,969.4 kg ha$^{-1}$) (Figure 6).

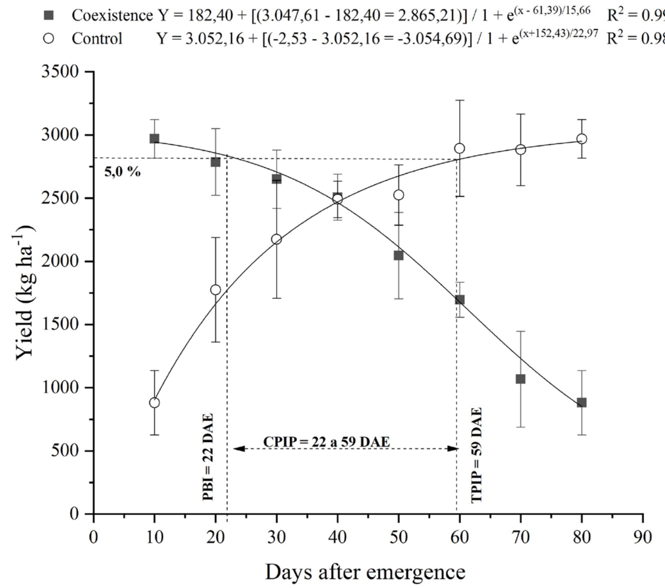
With increasing sowing density, the CPIP of the FPM experiment showed a reduction of four days compared to the CPIP of the TPM experiment. In addition, the PBI of the FPM experiment was seven days longer than the PBI of the TPM density treatments (Figures 5 and 6).

With regard to productivity at both densities, it is observed that the productivity of the treatment with permanent coexistence at TPM was 15.6% higher than at FPM. In addition,




PBI - period before interference; TPIP - total period interference prevention; and, CPIP - critical period for interference prevention.

**Figure 5.** Interference periods in common bean seeding density of 15 plants m$^{-1}$, considering a 5% yield loss.




PBI - period before interference; TPIP - total period interference prevention; and, CPIP - critical period for interference prevention.

**Figure 6.** Interference periods in common bean seeding density of 10 plants m$^{-1}$, considering a 5% yield loss.

when weed control was the entire crop cycle, yield was 14.7% higher at TPM density than at FPM density (Figures 5 and 6).

### Influence of weed dry mass on bean yield

When there was no dry mass accumulation of weeds, bean yield was lower in FPM (2,527 kg ha$^{-1}$) (Figure 7A) compared to TPM (2,786 kg ha$^{-1}$) (Figure 7B). Same values of total dry mass caused different responses in bean yield, showing slightly greater yield detriment at FPM density (Figure 7A) compared to TPM (Figure 7B).

As dry mass accumulation of the weed community and *Nicandra physaloides* increased, the rate of yield loss was slower in FPM compared to TPM (Figure 7A and 7B). The dry mass production of *Brachiaria plantaginea* in TPM was so low that for practical purposes it was considered null, while in FPM it was the second species with the highest dry mass production, also causing the exponential reduction of crop yield along with the other species (Figure 7A and 7B).

## Discussion

### Weed community composition

In both sowing densities, the Poaceae family stood out in the contribution of species, being that this family has a vast amount of species (11,500) of wide distribution in the world and of great economic, ecological and evolutionary importance, considered one of the most successful groups of plants (Hodkinson, 2018).

The similar amount of species in both densities means that the change from one density to another did not cause much diversification of species. Shrestha et al. (2002) stated that changes in the species diversity of a weed community is a long-term process resulting from the interaction of soil preparation, soil type, crop rotation, and weed management practices.

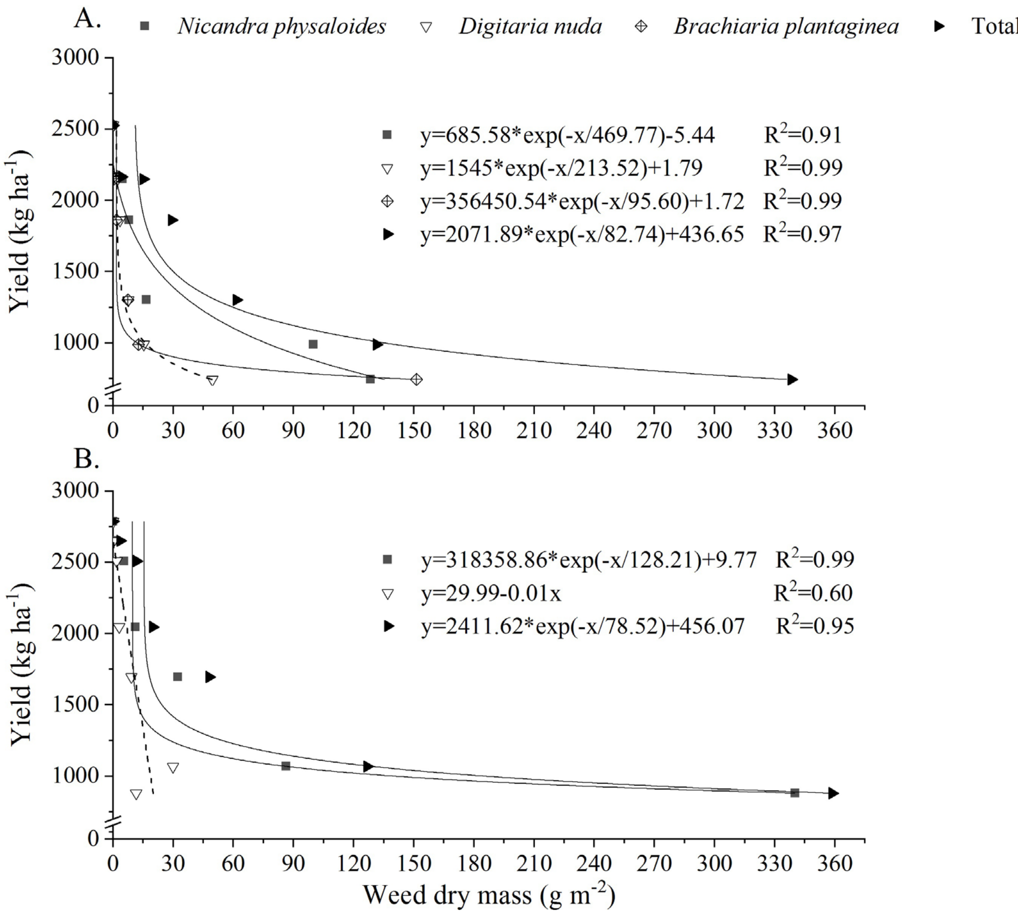



**Figure 7.** Bean yield as a function of weed dry mass (total and main species) at sowing density 15 (A) and 10 plants $m^{-1}$ (B).

### Weed density in coexistence periods

As coexistence time increases, resources become scarcer, increasing intra- and interspecific competition and resulting in few but competitive individuals at the end of the experiment (Parreira et al., 2014). This explains why the trend in the number of weed community individuals was decreasing with increasing coexistence periods in this study.

Some species had high density in the FPM treatments when coexisting, since the high coverage and favorable microclimate (high moisture retained in the soil) benefited the number of individuals, as was the case of *Digitaria nuda*, which can have germination above 50% under temperatures between 15 and 30 °C (Hugo et al., 2014), values that were recorded in this study and that explains the important presence of this species.

In the TPM experiment, the greatest highlight in relation to the number of individuals was for *Nicandra physaloides*, a species that found the right environment to establish itself as a result of the greater space and light, accelerating its development, although it is a species with slower germination flow and longer cycle compared to other species, such as *Eleusine indica* and *Digitaria nuda* (Uljol et al., 2018).

### Dry mass of weeds in coexistence periods

While weed density decreased, dry mass increased as a result of a few competitive individuals remaining until the final cycle of the bean plant. Lacerda et al. (2020) presented results of increasing trend of weed dry mass in coexistence periods similar to the present study.

In the FPM experiment *Nicandra physaloides* and *Brachiaria plantaginea* maintained high and increasing dry mass throughout the experiment, which harmed the crop due to the joint effect of both species. Lage et al. (2017) revealed that the *Bidens pilosa* + *Brachiaria plantaginea* consortium (147.5 plants $m^{-2}$ of each species) impacted bean more than the single species, causing the maximum reduction in the dry mass of leaves, stem, root, reproductive part, and growth rate of the crop.

*Nicandra physaloides* was most favored in the TPM treatments, where it produced greater dry mass compared to FPM, since in TPM there was more room for absorbing light, $CO_2$, water, and nutrients, and thus forming abundant biomass. Uljol et al. (2018) explained that *Nicandra physaloides* is very vigorous and of optimum cover production. Even at low density, it can accumulate large amounts of dry mass and stand out as the dominant species.

### Relative importance of weeds in coexistence periods

According to the density and dry mass values in the coexistence periods, *Nicandra physaloides* was expected to be the most important species at both seeding densities. However, under TPM density conditions, the relative importance (RI) was greater than in FPM due to having more space, light, and resources in general, especially in the initial periods of coexistence, which favored its establishment, thus becoming the main species competing with the bean plant. Authors such as Uljol et al. (2018) and Amaral et al. (2019) have also recorded high RI values of *Nicandra physaloides* at increasing coexistence periods in bell bell pepper and sugarcane, respectively, which highlights the great infesting capacity of the species in distinct agroecosystems.

*Brachiaria plantaginea* showed low, but increasing RI values throughout the FPM experiment. The high cover crop and weeds did not favor the development of the aforementioned species. According to CABI (2022), optimal crop cover can inhibit the germination and/or establishment of *Brachiaria plantaginea* seedlings. However, in the final period of the experiment, due to intense competition, the RI of *Nicandra physaloides* dropped slightly, which was taken advantage of by *Brachiaria plantaginea*, which showed a significant increase in RI.

The second species with the highest RI in the coexistence periods was *Digitaria nuda*, regardless of sowing density. Already Parreira et al. (2014) had reported *Digitaria* sp. as the second species with the highest RI in three common bean cultivars, standing out mainly in coexistence with the cultivar Pérola.

The RI balance in most species observed at 80 DAE with coexistence in FPM may be attributed to the high inter- and intraspecific competition under these conditions, there being insufficient resources for all species, this did not allow any particular species to stand out. The opposite occurred in the TPM experiment, where the smaller number of bean plants allowed more space and other resources to be available for the species that was most efficient in using them, in this case *Nicandra physaloides*.

### Interference periods

Sowing at high density (FPM) decreased CPIP compared to lower density (TPM), so the high plant population made the crop more competitive than some weed species, thus decreasing the time when the crop was more sensitive to weed community infestation. Parreira et al. (2011) asserted that the use of adequate spacing and sowing density can increase the competitive ability of the bean plant with respect to weeds because of rapid and better soil coverage, varying according to cultivar and soil and climate conditions. Additionally, short CPIP means less time controlling weeds, consequently the cost of control can be lower (reduced number of weeding, dose or frequency of post-emergent herbicide applications) compared to long CPIP.

In the TPM experiment, the long CPIP occurred because of the decreased competitive ability of the smaller bean population with the weed community. The species that took most advantage of this crop disadvantage was *Nicandra physaloides*, showing the highest average RI values in the TPM coexistence periods, compared to the FPM density. The success of the species was due to its excellent infestation capacity as a result of its larger size and abundant biomass and seed production, which adds the reservoir in the soil for future infestations. In addition, it is an allelopathic species, possessing pyrrolidine and tropanic alkaloids in the root, steroids in the leaves, and phenolic compounds in the fruit (Carrasco, 2019).

On the other hand, the high sowing density allowed the crop to live longer with the weeds in the early periods without experiencing significant losses in productivity, which meant the longer PBI in FPM than in TPM. Scholten et al. (2011) found in bean that the highest PBI (27 DAE) was with 0.45 m spacing and 15 plants $m^{-1}$ sowing density, when compared to 0.60 m spacing and 10 plants $m^{-1}$ density (13 DAE), a result similar to the present study.

However, this competitive advantage of the crop was not reflected in yields in FPM, due to increased intraspecific competition to infestation by *Fusarium oxysporum* f.sp. *phaseoli* (fusarium wilt) and *Xanthomonas phaseoli* pv. *phaseoli* (bacterial wilt). Both diseases affect the crop more when the soil has high humidity (Wendland et al., 2018; Paiva et al., 2020), conditions generated in the higher bean density in this study. In addition, the high temperatures during the water harvest intensified the problem in the mentioned density.

### Influence of weed dry mass on bean yield

The lower crop yield at FPM density in the absence of weeds was a result of intraspecific competition. Karavidas et al. (2022) stated that the genetic potential of common bean to form pods can be diminished by competition for space and nutrients caused by high sowing density. The greatest damage of weed community dry mass on the yield of bean was at density FPM compared to TPM, since the high crop population together with weed dry mass production gave rise to high competition, making resources increasingly scarce.

On the other hand, the rate of bean yield loss as a function of total dry mass and *Nicandra physaloides* (the main dry mass producing species) was slightly lower at FPM due to the greater competitive ability of the crop at the higher density, with yields at this density being less sensitive to weed dry mass increases.

Since there was a very low dry mass of *Brachiaria plantaginea* in TPM (practically it was zero), it did not compete with the other species, allowing *Nicandra physaloides* to produce a lot of dry mass, which dominated the surroundings. In FPM, the presence of *B. plantaginea* balanced the dry mass production of *N. physaloides* and *Digitaria nuda*, due to its high competitive capacity as a product of exceptional tiller production. According to Franceschetti et al. (2019), *B. plantaginea* affects photosynthetic activity and reduces dry mass per plant, number of pods per plant, number of grains per pod and mass of 1,000 grains of the common bean, decreasing productivity by 86%.

## Conclusions

Among the weeds of greatest relative importance in the density 10 and 15 plants $m^{-1}$ stand out: *Nicandra physaloides*, *Digitaria nuda*, and *Brachiaria plantaginea*.

As the sowing density increases from 10 to 15 plants $m^{-1}$, the critical period of interference prevention with 15 plants $m^{-1}$ decreases.

The period before interference increases with 15 plants $m^{-1}$, compared to the same period at a density of 10 plants $m^{-1}$.

The accumulation of weed dry mass exponentially decreases the yield of the crop, and this decrease is greater at a density of 15 plants $m^{-1}$.

The dry mass of the weeds *Nicandra physaloides*, *Digitaria nuda*, and *Brachiaria plantaginea* cause a large reduction in crop yields.

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## Compliance with Ethical Standards

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