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Competition limits of the yield components of the common bean 'BRS Ártico' with white grains

Limites de competição dos componentes de produtividade do feijão-comum 'BRS Ártico' de grãos brancos

Pedro Marques da SILVEIRA[1]; Luis Fernando STONE[2]

[1] Autor para correspondência. Engenheiro Agrônomo, Doutor, Embrapa Arroz e Feijão, GO 462, km 12, Santo Antônio de Goiás/GO- CEP 75375-000, pedro.silveira@embrapa.br

[2] Engenheiro Agrônomo, Doutor, Embrapa Arroz e Feijão, GO 462, km 12, Santo Antônio de Goiás/GO- CEP 75375-000, luis.stone@embrapa.br

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Abstract

The objective of this study was to determine the limits of competition of yield components and ideal plant population for the common bean cultivar BRS Ártico, with white grains. Five plant populations, resulting from the sowing of 7, 10, 13, 16 and 19 seeds per meter, were compared in an experiment conducted at Embrapa Rice and Beans, in the autumn-winter season of 2015, with an experimental design of randomized blocks with four replications. The yield was broken down into three components, number of plants ha^{-1} (NP), number of grains per plant (NGP) and grain weight (GW). An upper boundary curve, formed by a horizontal line and a hyperbola, was defined for each component as a function of the NP. The later the competition limit is determined in the cycle, the lower is its value, being equal to 190,000, 140,000 and 125,000 plants ha^{-1}, respectively, for number of pods per plant, NGP and GW. The maximum possible yield increases with NP to the lowest competition limit, 125,000 plants ha^{-1}, and after, there are adjustments between successive components, stabilizing this yield regardless of NP.

Additional keywords: grains per plant; grain weight. *Phaseolus vulgaris;* pods per plant.

Resumo

O objetivo deste trabalho foi determinar os limites de competição dos componentes da produtividade e a população ideal de plantas para a cultivar de feijão-comum BRS Ártico, de grão branco. Cinco populações de plantas, resultantes da semeadura de 7, 10, 13, 16 e 19 sementes por metro, foram comparadas em experimento conduzido na Embrapa Arroz e Feijão, na safra de outono-inverno de 2015, no delineamento experimental de blocos ao acaso, com quatro repetições. A produtividade foi decomposta em três componentes: número de plantas ha^{-1} (NP), número de grãos por planta (NGP) e massa dos grãos (MG). Uma curva limite superior, formada por uma reta horizontal e uma hipérbole, foi definida para cada componente em função de NP. O limite de competição de um componente é mais baixo quanto mais tarde no ciclo ele for determinado, sendo igual a 190.000, 140.000 e 125.000 plantas ha^{-1}, respectivamente, para número de vagens por planta, NGP e MG. A produtividade máxima possível aumenta com NP até o limite de competição mais baixo, de 125.000 plantas ha^{-1}, e, após, ocorrem ajustamentos entre os componentes sucessivos, estabilizando essa produtividade, independentemente de NP.

Palavras-chave adicionais: grãos por planta; massa dos grãos; *Phaseolus vulgaris;* vagens por planta.

Introduction

Brazil is the largest world producer of common bean (*Phaseolus vulgaris* L.), with a production of about 2.7 million tonnes in 2014 (Embrapa, 2018). Carioca and black beans are the most cultivated, corresponding to 70% and 15% of the national production, respectively (CTSBF, 2010). These grains belong to the Mesoamerican race and have 100-grain weight lower than 25 g, being considered small according to the classification of Blair et al. (2010).

Common beans with white, red, cream, yellow tegument, among others, with presence or absence of streaks or stripes of other colors, and with medium (25 to 40 g per 100 grains) or large size (> 40 g per 100 grains), according to Blair et al. (2010), are known as special-grain beans. Included in this group are the Andean beans, which have very early production in Brazil due to the lack of adapted cultivars with high grain yield (Ribeiro et al., 2014a).

Special grains, however, may represent marketing advantages for bean producers (Ribeiro et al., 2014b), since they have a good demand in the international market, especially the white, red and the striped - having cream tegument with red stripes (Thung et al., 2009), and are sold at prices that exceed two times or more the price of carioca and black beans (Ribeiro et al., 2014a).

In this sense, Embrapa Rice and Beans recently released the common bean cultivar BRS Ártico, with white grains, originating from the line WAF 75. This cultivar was recorded for the winter season in the states of Goiás, Federal District, Mato Grosso, Tocantins, Maranhão, Bahia, Espírito Santo and Rio de Janeiro; and for the 'wet' and 'dry' seasons in the state of Paraná (Pereira et al., 2016). For its cultivation to be more efficient, however, it is necessary to know in depth the effect of plant populations on yield and its components, as for Brazilian conditions this information is scarce regarding special beans with large size grains.

The yield components may be limited by the number of plants or grains per hectare, if these are sufficiently high to cause competition for resources. The value of the first component, number of plants per hectare, often determines the maximum value of the next component and, finally, the maximum possible yield (Wey et al., 1998). Knowledge of the competition limits of yield components is important in determining the optimal plant population (Stone & Silveira, 2008).

Wey et al. (1998) developed a method to determine the competition limits of yield components that does not exclude the compensation effects between these components, but they can not exceed the strict compensation. The aim of this study was to use this method to determine the competition limits of yield components of the common bean cultivar BRS Ártico and the ideal plant population for this cultivar.

Material and methods

The experiment was conducted in the experimental area of Embrapa Rice and Beans, in the Capivara Farm, in Santo Antônio de Goiás, GO, whose geographical coordinates are: 16º 28' 00" S latitude and 49º 17' 00" W longitude, and altitude of 823 m. It was implemented in an Acric Red Latosol, clayey, with 440 g ha^{-1} sand, 140 g ha^{-1} silt and 420 g ha^{-1} clay, in the autumn-winter 2015.

It was used the experimental design of randomized blocks with five treatments and four replications. The treatments consisted of five plant populations resulting from the use in the sowing of 7, 10, 13, 16 and 19 seeds per meter.

Sowing was performed manually in 0.45 m spaced furrows, opened in the experimental area conducted under no-tillage, previously cultivated with corn. The cultivar used was BRS Ártico, which has semi-early cycle (75-84 days from emergence to physiological maturity). The plants of this cultivar are shrubby, with determinate growth habit type I. With regard to plant architecture, 'BRS Ártico' is upright and shows good tolerance to lodging. Notwithstanding, due to the low height of the plant, provisos should be considered to perform direct mechanical harvesting. The flowers are white and in the physiological maturity the pods are yellowish green. In the harvest maturity stage, the pods are straw yellow, and may be slightly reddish. The beans are white, with a full oblong shape and intermediate brightness (Pereira et al., 2016).

Prior to the planting of beans, carried out in 06/24/2015, the area was desiccated with glyphosate, using 2.4 kg ha^{-1} a.i. Fertilization was performed mechanically, at the opening of the furrows, using 400 kg ha^{-1} of the formula 5-30-5 (N-P_2O_5-K_2O). The plots were 1.80 m wide x 5 m long. Twenty days after plant emergence, day 07/20/2015, nitrogen topdressing fertilization was performed with 90 kg ha^{-1} nitrogen in the form of urea. The experimental area was irrigated by sprinkling, with a center pivot system, and phytosanitary treatment in beans were made when necessary. At harvest, carried out in 09/15/2015, two central rows of the plot were harvested, disregarding 0.5 m of the ends.

In each plot, it were performed the count of the number of plants (NP) and pods (NPo) at harvest and the direct determination of yield (YIELD) and moisture content of grains. The mean unit grain weight (GW) was obtained from a batch of 100 grains. The weights were corrected to 13% moisture. The number of grains per hectare (NG) was obtained by dividing the YIELD by the GW, the average number of pods per plant (NPP) by dividing the NPo by the NP and the average number of grains per plant (NGP) by dividing the NG by the NP.

Regression analysis was performed between grain yield and number of plants per hectare. Additionally, the data analysis was performed using the method presented in Wey et al. (1998), which considers the compensation effects between yield components. Thus, the yield was expressed by:

$$\text{YIELD} = \text{NP} \times \text{NGP} \times \text{GW} \quad (1)$$

wherein each component is representative of the stage in which it is established. Therefore, NP is representative of the vegetative stage, NGP relates to flowering and GW relates to maturation.

It were examined the relationships between NP x NPP, NP x NGP and NG x GW. The boundary lines of these relationships consist of a horizontal line followed by a hyperbola, forming an envelope curve (Figure 1). The corresponding equations were calculated after adjusting the boundary lines to the data. The horizontal line was adjusted by the point of greatest value of the Y-axis (y_{max}). The hyperbola has been set by the point where the product of the xy coordinates was maximum (xy_{max}).

For each component, the competition limit (L) was determined:

$$L \approx xy_{max}/y_{max} \quad (2)$$

which is the abscissa point corresponding to the intersection between the horizontal line and the hyperbola. L was calculated using the set of equations obtained for the two components of the boundary line.

It was assumed that the maximum value of a component is determined by the values of the components previously established. The value of the first component (NP), hence, has set the upper limit for the second and so on. NP determined NGP and those determined GW. The product of these successive values has determined the maximum grain yield for each value of NP ($Y_{M/NP}$). The highest maximum yield obtained (Y_{max}) was considered an estimate of Y_{rad}, which is the maximum possible yield for the prevailing conditions of radiation and temperature.

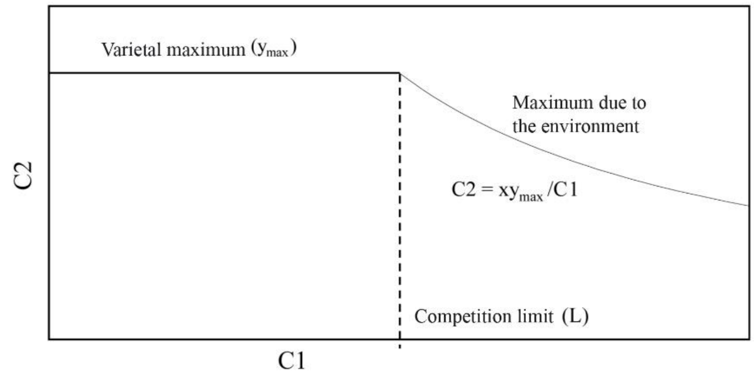
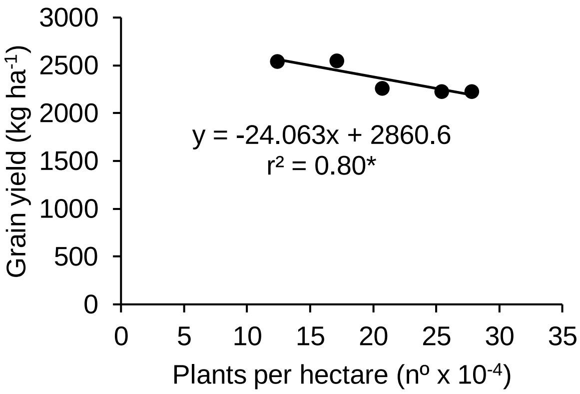


Figure 1 - Theoretical representation of the relation to the maximum (envelope curve) of two successive yield components, C1 and C2, being C1 a component related to the area.

Results and discussion

Through the regression analysis, it is found that yield decreased as the number of plants per hectare increased (Figure 2). Nonetheless, it is observed, in this figure, that for the two lowest populations of plants, the average yields were similar; the same can be observed with the yield in the three largest populations of plants. This probably is due to the compensation capacity between the yield components.



***** Significant at 5% probability

Figure 2 - Grain yield of common bean ‘BRS Ártico’ as function of the number of plant per hectare.

To detail the compensation effects between the yield components, it was used the method shown in Wey et al. (1998). The envelope curves of the pairs of yield components and the competition limits established for the number of pods per plant (LNPP), number of grains per plant (LNGP) and grain weight (LGW) are shown in Figure 3.

It is observed that the maximum number of pods per plant is constant below the population of 190.000 plants ha^{-1} (LNPP) and, according to the model, it can not exceed the value of 23.7 if the plant population increases more (Figure 3a). Similarly, the maximum number of grains per plant, 50.2 (Figure 3b), is constant below the population of 140.000 plants ha^{-1} (LNGP). The maximum grain weight was equal to 0.487 g (Figure 3c), being constant below 6,300,000 grains ha^{-1}, and the minimum value was 0.440 g, for the maximum population of 7.03 million grains ha^{-1}.

Ribeiro et al. (2014b), in two locations of the RS state, in the sowings performed in October (season) and February (off-season), had an average number of pods per plant for the line WAF 75 ranging from 7.1 to 14.6, number of grains per pod ranging from 2.3 to 3.3 and mean grain weight ranging from 0.345 to 0.556 g. These authors also observed that the grain weight showed a negative correlation with the number of grains per plant and the number of grains per pod, considering the set of special-grain beans lines assessed. This shows the existence of great plasticity between the yield components of common bean grains, resulting in compensation capacity.

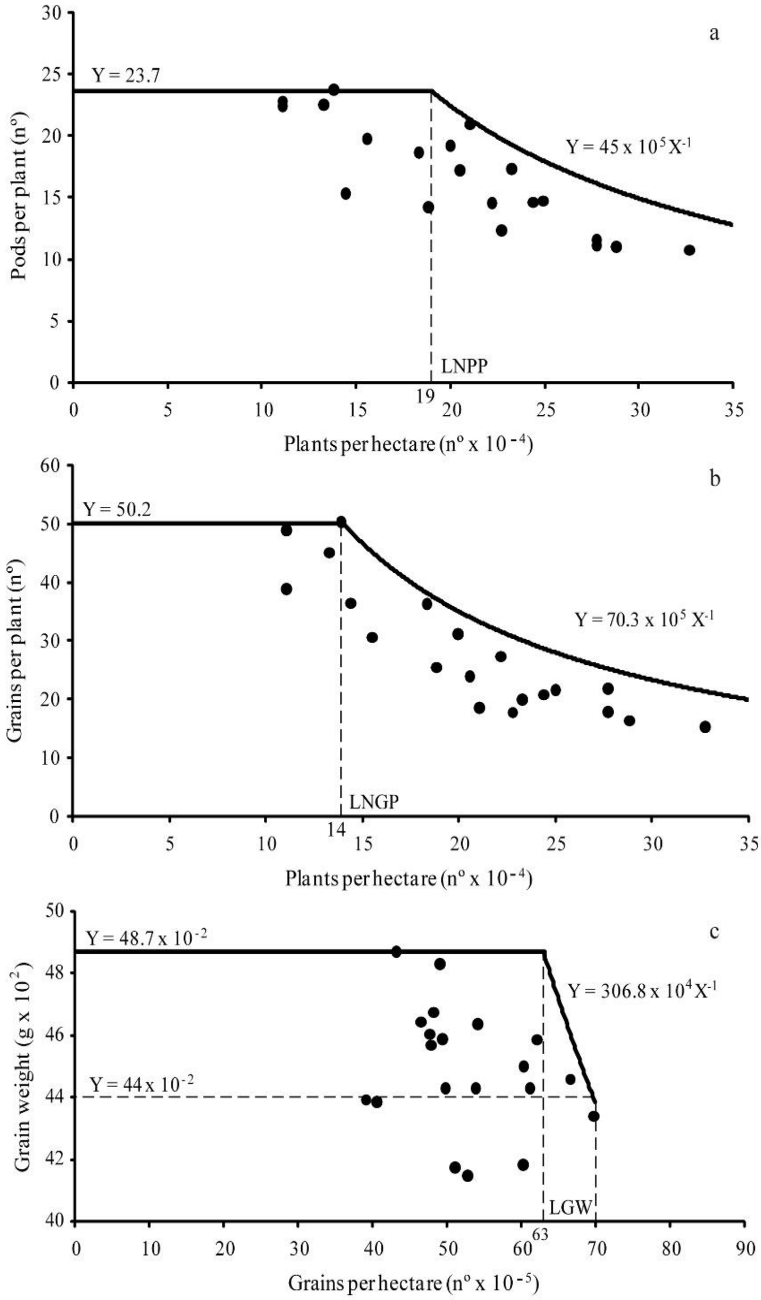


Figure 3 - Limit lines of the relationships among the yield components of common bean ‘BRS Ártico’. (a) LNPP – competition limit for number of pods per plant, (b) LNGP – competition limit for number of grains per plant and (c) LMG – competition limit for grain weight.

The relationship between NG and NP (Figure 4a) was derived from Figure 3b. As for a specific NP value there is a single corresponding maximum NG value, it was calculated the relationship of the competition limit LGW with NP. The NG value in which LGW is reached is indicated in Figure 3c; the NP value corresponding to this LGW value is calculated in Figure 4a. Thus, the competition limit between the grains may be expressed not only as a NG function but also as a NP function (Figure 4b), the grain weight being maximum and constant below the population of 125.000 plants ha^{-1} (LGW).

The limit populations are related to the developmental stage at which the yield component is established. The number of pods per plant is determined between pre-flowering and early flowering, when the canopy is not completely closed. The number of grains per plant, in turn, is determined when the canopy is closed and the plant's demand for external resources is high. The competition limit for the grain weight is yet smaller, indicating more intense competition, which can be due to progressive senescence of leaves, which reduces the utilization efficiency of the intercepted radiation, causing increased competition for assimilates between grains due to supply limitation (Stone & Silveira, 2008).

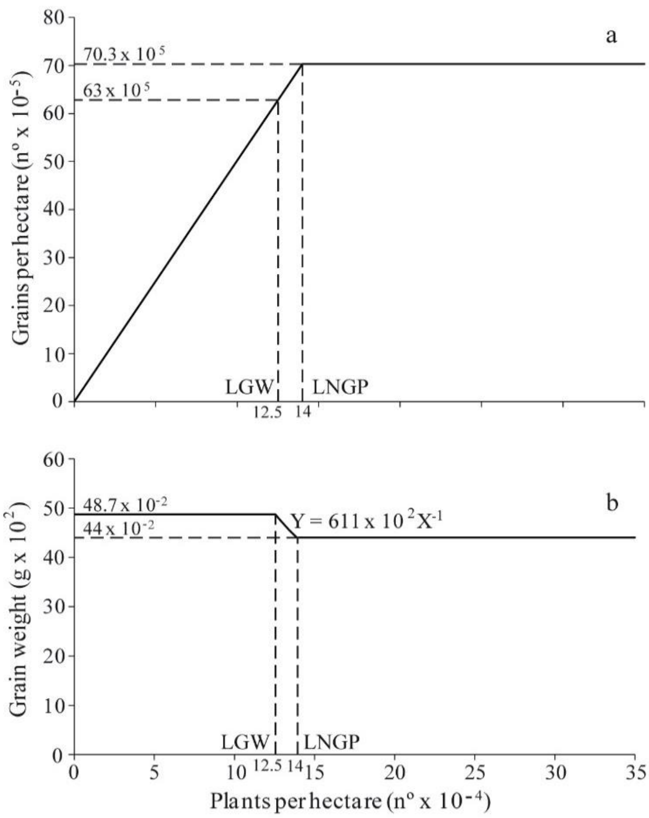


Figure 4 - Expression of the competition limit for the number of grains per plant (LNGP) and the grain weight (LGW), and the number of grains per hectare (a) and grain weight (b), as a function of the plant population of the common bean 'BRS Ártico'.

The great plasticity between the yield components of the bean grains causes the yield to remain stable in a wide range of plant population, which was also observed by Stone & Silveira (2008), for the cultivar "Pérola". Under the LGW, there is no competition between plants. The number of grains per plant and its unit weight are independent of the plant population, with which yield is related linearly (Figure 5). Between LGW and LNGP, the number of pods per plant and the number of grains per plant remain constant (Figures 3a and 3b), but the number of grains per hectare increases with plant population (Figure 4a), while grain weight decreases (Figure 4b). The maximum yield no longer increases (Figure 5). Above the LNGP, the number of grains per plant decreases with increasing plant population (Figure 3b), the grain weight and the number of grains per hectare stabilize (Figures 4a and 4b), and yield is constant (Figure 5). Above the LNPP, the number of pods per plant decreases with increasing plant population (Figure 3a), but without affecting yield (Figure 5). The curve plateau of the yield corresponds to the highest maximum yield, which is theoretically equal to the yield due to radiation and temperature.

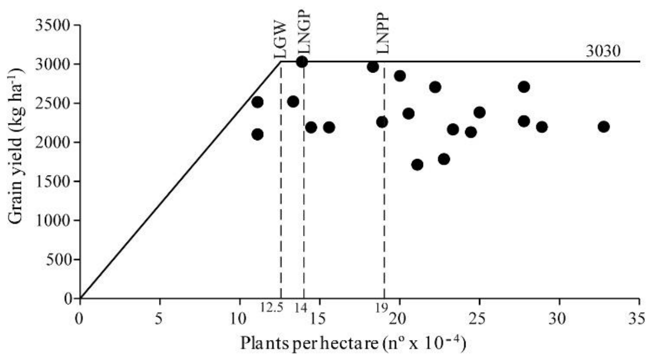


Figure 5 - Maximum calculated and measured grain yields of common bean 'BRS Ártico'. LGW – competition limit for grain weight, LNGP – competition limit for number of grains per plant and LNPP – competition limit for number of pods per plant.

The maximum grain yield observed, 3,030 kg ha^{-1} (Figure 5), was above the yield potential of 2,677 kg ha^{-1} reported by Pereira et al. (2016). Thus, the graphical representations of the relationship between yield components include situations with yields close to maximum, allowing positioning accurately the boundary lines for the point cloud.

The great plasticity of the yield components caused grain yield to remain stable in a wide range of plant population, which was also observed by Stone & Silveira (2008), for Pérola cultivar. Corroborating this result, Pérez et al. (2010), for the white bean cultivar Aluyori, with 100-grain weight greater than 50 g and yield potential of 3,000 kg ha^{-1}, also found that high yields under irrigation were obtained in a plant population range varying from 150,000 to 200,000 plants ha^{-1}.

Conclusions

The later the determination of a component in the cycle, the lower the competition limit, being equal to 190,000, 140,000 and 125,000 plants ha^{-1}, respectively, for the number of pods per plant, number of grains per plant and grain weight. The maximum possible yield increases with plant population to the lowest competition limit, 125,000 plants ha^{-1}, and after, there are adjustments between successive components, stabilizing this yield regardless of plant population.

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