e-ISSN 1983-4063 - *www.agro.ufg.br/pat* - Pesq. Agropec. Trop., Goiânia, v. 54, e78404, 2024

Research Article

Nutrient extraction and export by determinate and indeterminate common bean cultivars[1]

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ABSTRACT

There is evidence that the dry mass and nutrient accumulation rates of earlier (determinate) cultivars are faster than those of normal or late cycle (indeterminate). This study aimed to quantify the nutrient extraction and export and calculate the harvest index of determinate and indeterminate common bean cultivars. A randomized block design was used, with four replicates and eight cultivars (BRS FC104, TAA Gol, BRS Estilo, BRSMG Uai, IPR Tuiuiú, BRSMG Marte, Pérola and TAA Dama). The accumulation of dry matter and nutrients at the vegetative and reproductive stages, grain yield and grain nutrient export were determined. The early cultivars TAA Gol and BRS FC104 (Type I - determinate) accumulated more dry matter and nutrients during the vegetative stage than the indeterminate types II and III. However, from R7, no differences were observed among the cultivars for extractions or nutrient exports and harvest index. The cultivars exported 33, 11, 17, 2.3, 2.2 and 1.5 kg t^{-1} of grain for N, P_2O_5, K_2O, S, Mg and Ca, respectively. Micronutrient exports were 14, 3.7, 70, 13 and 34 g Mg^{-1} of grain for B, Cu, Fe, Mn and Zn, respectively. The TAA Gol and BRS FC104 determinate cultivars reached the R9 stage at 77 days and the indeterminate cultivars at 85 (BRSMG Marte), 90 (IPR Tuiuiú and BRSMG Uai) and 93 days (TAA Dama and Pérola). BRS Estilo, BRS FC104 and TAA Gol had the lowest grain yield (< 2,200 kg ha^{-1}) and TAA Dama the highest grain yield (3,275 kg ha^{-1}).

KEYWORDS: *Phaseolus vulgaris* L., early cultivars, harvest index.

RESUMO

Extração e exportação de nutrientes por cultivares determinadas e indeterminadas de feijão-comum

Há evidências de que as taxas de acúmulo de massa seca e nutrientes das cultivares mais precoces (determinadas) são mais rápidas do que aquelas de ciclo normal ou tardio (indeterminado). Objetivou-se quantificar a extração e exportação de nutrientes e o índice de colheita de cultivares de feijão-comum determinadas e indeterminadas. Utilizou-se delineamento em blocos casualizados, com quatro repetições e oito cultivares (BRS FC104, TAA Gol, BRS Estilo, BRSMG Uai, IPR Tuiuiú, BRSMG Marte, Pérola e TAA Dama). Foram determinados o acúmulo de massa seca e de nutrientes nos estádios vegetativo e reprodutivo, produtividade e exportação de nutrientes. No início do estádio vegetativo, as cultivares precoces TAA Gol e BRS FC104 (tipo I - determinadas) apresentaram maior acúmulo de massa seca e nutrientes do que as indeterminadas tipos II e III. No entanto, a partir de R7, não houve diferenças entre as cultivares nas extrações, bem como nas exportações de nutrientes e no índice de colheita. Foram exportados 33; 11; 17; 2,3; 2,2; e 1,5 kg t^{-1} de grão de N, P_2O_5, K_2O, S, Mg e Ca, respectivamente. No caso dos micronutrientes, foram 14; 3,7; 70; 13; e 34 g Mg^{-1} de grão de B, Cu, Fe, Mn e Zn. As cultivares determinadas TAA Gol e BRS FC104 atingiram o estádio R9 aos 77 dias e as indeterminadas aos 85 (BRSMG Marte), 90 (IPR Tuiuiú e BRSMG Uai) e 93 dias (TAA Dama e Pérola). BRS Estilo, BRS FC104 e TAA Gol apresentaram as menores produtividades (< 2.200 kg ha^{-1}) e TAA Dama a maior produtividade (3.275 kg ha^{-1}).

PALAVRAS-CHAVE: *Phaseolus vulgaris* L.; cultivares precoces; índice de colheita.

INTRODUCTION

Approximately 33 million hectares of common bean (*Phaseolus vulgaris* L.) are grown per year worldwide, with an average yield below 1,000 kg ha^{-1} (FAO 2021). The average yield of common bean in Brazil and worldwide is low, and Moreira et al. (2018) state that Brazil has potential for average yields greater than 3,000 kg ha^{-1}. Nascimento et al. (2021) evaluated modern cultivars used in Brazilian crop fields under conditions similar to those in this study and found yields above 1,600 kg ha^{-1}, even in situations without topdressing fertilization. Moreira et al. (2023), for example, observed yields near 3,000 kg ha^{-1} on Brazilian farms under rainfed cultivation when no-till, crop rotation and adequate

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[1] Received: Jan. 30, 2024. Accepted: Apr. 30, 2024. Published: May 29, 2024. DOI: 10.1590/1983-40632024v5478404.

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management were used. Furthermore, thanks to breeding programs established by Brazilian public institutions, cultivars resistant to the main diseases that affect the crop and with yield potential have been made available to producers in recent years (Nunes et al. 2021).

One of the major obstacles to increasing the average yield of this crop is the lack of information on nutritional requirements of newly released cultivars. A search in the Web of Science database, in January 2024, for the expressions "*Phaseolus vulgaris*" and "nutrient requirements" returned 80 results, whereas, for maize, there were 826, and 938 for soybean. For the common bean crop, approximately 70 % of the articles were published more than five years ago. Among the most recent publications, four are review articles (Atique-Ur-Rehman et al. 2018, Dawson et al. 2019, Fernández-López et al. 2020, Justes et al. 2021), and few of them addressed the issue of nutrient extraction by common bean cultivation (Fernandes et al. 2013, Soratto et al. 2013, Nascente et al. 2016a, Nascente & Carvalho 2018, Nyoki & Ndakidemi 2018, Silva & Moreira 2022).

When entering the keywords "nutrient uptake" and "*Phaseolus vulgaris*" into the same database, 198 articles from the field of agriculture were found. The first record is an article by Dormaar (1975) on the extraction of nutrients by the common bean crop. Vasconcelos et al. (2020) studied only the Pérola cultivar, which was released in 1996 (Yokoyama et al. 1999), and Silva & Moreira (2022) worked with just four cultivars. Not only is the number of studies limited, but common bean cultivars have also shown different dry matter accumulation rates, nutrient extraction and export rates, and harvest indices, according to cycle length, commercial group and plant growth type (Nascente et al. 2016a, Nascente et al. 2016b, Zilio et al. 2017, Nascente & Carvalho 2018, Leal et al. 2019, Silva & Moreira 2022).

Although there are four types of common bean growth habits, studies comparing the amounts of nutrients extracted and exported by each of these types are rare (Silva & Moreira 2022). Types I, II and III are used to produce dry edible beans, while type IV is cultivated for green edible beans. Type I (determinate growth habit) cultivars reach developmental stages earlier and complete all stages more quickly than types II, III and IV, which have an indeterminate growth habit. Regarding plant architecture, type I plants are upright, type II are semi-upright, and types III and IV are prostrate (Oliveira et al. 2018). Therefore, the aim of this study was to quantify the extraction and export of nutrients and calculate the harvest index of common bean cultivars with three growth habits (types I, II and III) belonging to various commercial groups. Our hypothesis was that earlier maturity common bean cultivars (type I) would have a higher initial dry matter yield than indeterminate cultivars (types II and III) and, therefore, a greater need for nutrients in the initial phase than later maturity cultivars do (types II and III).

MATERIAL AND METHODS

The experiment was carried out in a clayey Typic Hapludox (USDA 2014), at the Universidade Federal de Lavras, in Lavras, Minas Gerais state, Brazil (21º14'43"S, 44º59'59'W and altitude of 919 m), in the 2018/2019 crop season.

The experiment followed a randomized block design, with four replicates and eight treatments: cultivars of different types of growth habit (type I: BRS FC104 and TAA Gol; type II: BRS Estilo, BRSMG Uai, IPR Tuiuiú and BRSMG Marte; and type III: Pérola and TAA Dama). Each plot had an area of 28.8 m^2 and consisted of eight 6-m-long rows spaced at 0.6 m. The four central rows were used for data collection, leaving a 1-m border at each end of the rows, for a total of 9.6 m^2. Plants in two rows of the data collection area were examined at the different phenological stages of the crop, and those in the other two rows were used to estimate the final grain yield.

During the experimental period, the mean temperature was 23.5 ºC, the minimum 13.5 ºC and the maximum 34.2 ºC. The cumulative rainfall from sowing to harvest of the late maturity cultivars (Jan. 22, 2019) was 714.4 mm, while, during the cycle of the early maturity cultivars (type I), it was 691.0 mm (Figure 1).

The chemical characterization of the 0-20 cm soil layer before starting the experiment resulted as it follows: pH (H_2O) = 6.5; P (Mehlich-1) = 4.6 mg dm^{-3}; K = 118 mg dm^{-3}; organic matter = 36 g kg^{-1}; Ca = 4.0 $cmol_c$ dm^{-3}; Mg = 1.4 $cmol_c$ dm^{-3}; Al = 0.00 $cmol_c$ dm^{-3}; H + Al = 1.5 $cmol_c$ dm^{-3}; CEC at pH 7.0 = 7.3 $cmol_c$ dm^{-3}. Base saturation was 79 %; B = 0.24 mg dm^{-3}; Cu = 0.5 mg dm^{-3}; Fe = 47.6 mg dm^{-3}; Mn = 8.6 mg dm^{-3}; S = 4.9 mg dm^{-3}; and Zn = 3.4 mg dm^{-3}.

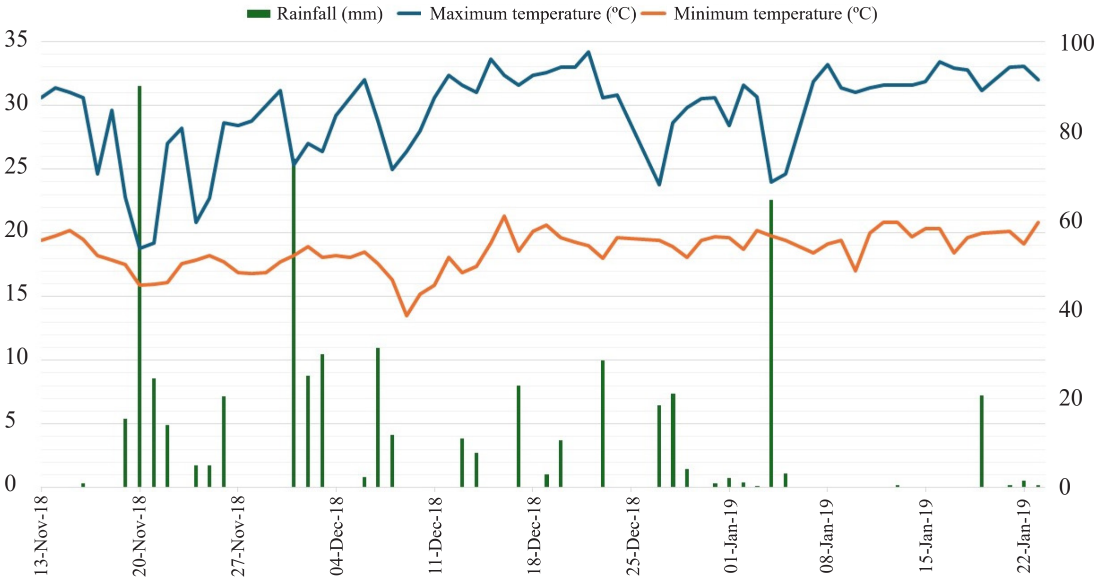


Figure 1. Rainfall and maximum and minimum temperatures for the experiments performed during the 2018/2019 crop year (Lavras, Minas Gerais state, Brazil).

The fertilization and phytosanitary management are detailed in Moraes (2023). The sowing density was 270 (type I), 220 (type II) and 170 (type III) thousand seeds ha^{-1}, as recommended by Araújo & Camelo (2015). To evaluate the nutrient accumulation, two plants were collected per plot in each season, discarding the two plants closest to the previous collection site, in the following phenological stages: V4 (3, 5 and 7 trifoliate leaves), R5, R7, R8 and R9. The developmental scale used for the bean plants in this study was that described in Oliveira et al. (2018), which divides the biological cycle into the vegetative and reproductive phases. These, in turn, are subdivided into ten stages. The vegetative phase (V) consists of stages V0 (germination), V1 (emergence), V2 (primary leaves), V3 (first open trifoliate leaf) and V4 (third open trifoliate leaf); and the reproductive phase (R) includes the stages R5 (flower budding), R6 (flowering), R7 (pod formation), R8 (grain filling) and R9 (physiological maturity).

In each evaluation, the plants were cut close to the soil and, according to each stage, separated into leaves, stems, pods and grains. The collection stage and procedures are described in Table 1. After the collections, the accumulations of dry matter and total nutrients in each phenological stage, as well as the export of nutrients by the grain, were determined. For this analysis, the plant material was dried in an

Table 1. Accumulation of total dry matter in the vegetative and reproductive stages of common bean, grain yield and harvest index (HI) of different cultivars.

Cultivar	V4.3	V4.5	V4.7	R5	R7	R8	R9	Yield	HI
	kg ha^{-1}								%
TAA Dama	334 b*	409 b	1,044 a	2,102 a	2,797 a	3,370 a	6,866 a	3,275 a	47 a
BRS Estilo	338 b	569 a	673 b	680 c	3,361 a	4,646 a	5,440 b	2,031 b	38 a
BRS FC104	514 a	817 a	894 a	1,220 b	4,026 a	5,546 a	4,355 b	2,134 b	49 a
TAA Gol	654 a	610 a	921 a	1,266 b	3,979 a	5,864 a	5,130 b	2,167 b	42 a
BRS Marte	210 b	379 b	500 b	942 c	2,767 a	5,083 a	6,351 a	2,974 a	47 a
Pérola	395 b	556 a	1,206 a	2,370 a	3,513 a	4,054 a	5,378 b	2,751 a	51 a
IPR Tuiuiú	402 b	599 a	501 b	2,090 a	2,435 a	3,999 a	6,177 a	3,150 a	51 a
BRSMG Uai	304 b	488 b	465 b	2,122 a	3,303 a	3,838 a	6,543 a	2,735 a	42 a
CV (%)	29.7	30.3	31.6	15.3	22.4	29.5	28.1	20.46^{+}	7.16^{+}

* Means followed by the same letter in the column do not differ from each other according to the Scott-Knott test at 5 % of significance. $^{+}$ Transformed data; CV: coefficient of variation; V4.3, V4.5 and V4.7: plants with 3, 5 and 7 trifoliate leaves, respectively.

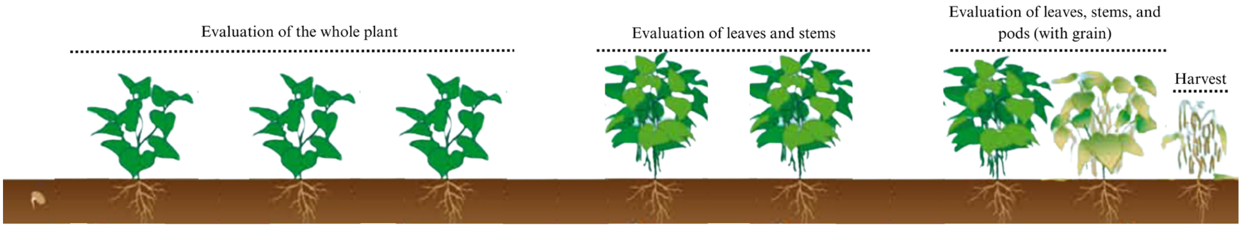
oven at 65 ºC, ground and sent to the laboratory for chemical analysis of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn. Grain yield was determined by harvesting grains from plants in two 6-m-long rows, and grain moisture was standardized to 13 % (Malavolta et al. 1997).

The harvest index was estimated by the following calculation: (grain dry matter/total dry matter) × 100. The grain dry matter and total dry matter of the R9 stage were considered. The total life cycle of each cultivar considered the time from the V0 to the R9 stage. The number of days in the vegetative stage was considered the interval from V0 to R5. The reproductive stage, in turn, was from R5 to R9. The R9 of each cultivar was considered the day on which 70 % of the pods of each plant were mature, that is, the pre-harvest desiccation point.

For each phenological stage, the experimental data were examined to determine if they met the assumptions of analysis of variance, and analysis of variance was used to verify differences in nutrient uptake among the cultivars. When necessary, the data were transformed by √*x*. When there was a significant effect, the means were grouped by the Scott-Knott test at 5 % of probability. Differences among the growth types (type I: BRS FC104 and TAA Gol; type II: BRS Estilo, BRSMG Uai, IPR Tuiuiú and BRSMG Marte; and type III: Pérola and TAA Dama) were also determined. All data expressed in the tables are original data.

RESULTS AND DISCUSSION

The type I determinate cultivars TAA Gol and BRS FC104 reached the R9 stage (maturity) at 77 days. As for the type II indeterminate cultivars, BRSMG Marte achieved this cycle at 85 days, and the IPR Tuiuiú and BRSMG Uai cultivars had a 90-day cycle. The type III indeterminate cultivars TAA Dama and Pérola reached their cycle at 93 days (Figure 2). This difference in cycle closure among cultivars was expected, because it is well attested in the literature that indeterminate cultivars have a longer cycle than determinate ones (Singh 1981, Oliveira et al. 2018). In addition, regardless of the growth habit and type of cultivar, variation in the cycle may depend on the region, as well as the season in which common bean is grown, as the plant is very sensitive to temperature variations (Heinemann et al. 2022), which affect the accumulation of degree-days (Silva & Moreira 2022). The cultivar cycles observed in this study are within the range of average values found in the



Stage V4.3*		V4.5		V4.7		R5		R7		R8		R9	
Cultivar	**Date**	**Cultivar**	**Date**	**Cultivar**	**Date**	**Cultivar**	**Date**	**Cultivar**	**Date**	**Cultivar**	**Date**	**Cultivar**	**Date**
BRS FC104 TAA Gol	11/14/18	BRS Estilo BRS FC104 TAA Gol BRSMG Marte	11/23/18	BRS Estilo BRS FC104 TAA Gol BRSMG Marte	11/26/18	BRS Estilo BRS FC104 TAA Gol BRSMG Marte	11/30/18	BRS FC104 TAA Gol	12/10/18	BRS FC104 TAA Gol	12/17/18	BRS FC104 TAA Gol	01/09/19
BRS Estilo BRSMG Uai IPR Tuiuiu Pérola TAA Dama BRSMG Marte	11/20/18	BRSMG Uai IPR Tuiuiu Pérola TAA Dama	11/26/18	BRSMG Uai IPR Tuiuiu Pérola TAA Dama	11/30/18	BRSMG Uai IPR Tuiuiu	12/03/18	BRS Estilo BRSMG Uai IPR Tuiuiu Pérola TAA Dama BRSMG Marte	12/17/18	BRS Estilo BRSMG Uai IPR Tuiuiu Pérola TAA Dama BRSMG Marte	12/20/18	BRSMG Marte	01/17/19
						Pérola TAA Dama	12/05/18					BRS Estilo BRSMG Uai IPR Tuiuiu Pérola TAA Dama	01/22/19

Cultivar	vegetative cycle	reproductive cycle	total cycle	**Cultivar**	vegetative cycle	reproductive cycle	total cycle
BRS FC104	(36 DAS)	(41 DAS)	77 days	BRSMG Uai	(39 DAS)	(51 DAS)	90 days
TAA Gol	(36 DAS)	(41 DAS)	77 days	IPR Tuiuiu	(39 DAS)	(51 DAS)	90 days
BRSMG Marte	(36 DAS)	(49 DAS)	85 days	Pérola	(41 DAS)	(52 DAS)	93 days
BRS Estilo	(36 DAS)	(54 DAS)	90 days	TAA Dama	(41 DAS)	(52 DAS)	93 days

Figure 2. Vegetative, reproductive and total cycles of each cultivar used, and stages at which the whole plants and plant components were collected. * V4.3, V4.5 and V4.7: plants with 3, 5 and 7 trifoliate leaves, respectively. DAS: days after sowing. The part of the figure containing the plants was modified from Oliveira et al. (2018).

literature (Nascente et al. 2016a, Nascente et al. 2016b, Nascente et al. 2016c, Nascente & Carvalho 2018, Silva & Moreira 2022), but type III cultivars may require 115 (Oliveira et al. 2018) or more days in situations where average temperatures are below the optimum (17-32 ºC) for the crop (Heinemann et al. 2022).

The total dry matter yield varied among the cultivars during the vegetative and early reproductive stages (R5: flower budding). The dry matter yield at the beginning of the vegetative stage was higher for the early cultivars (type I), TAA Gol and BRS FC104 than for the indeterminate cultivars with a longer cycle (types II and III) (Table 1), what is related to their more accelerated maturation (Singh 1981, Nascente et al. 2016a). The late cultivars (type III) had higher dry matter values than the early cultivars only close to flowering (R5: flower budding), after the vegetative phase. This was expected, since the early cultivars have determinate growth, with fast initial growth and termination of vegetative growth after flowering, whereas type III cultivars (indeterminate) continue to grow and produce new leaves after the beginning of flowering (Oliveira et al. 2018). However, from the R7 to the R9 stage, there were no differences in the accumulated dry matter among the cultivars (Table 1).

The cultivars from the carioca and type I groups produced an average of 4,355 (BRS FC 104) and 5,129 kg ha^{-1} (TAA Gol) of dry matter at the end of the cycle, similarly to the amount produced by the Pérola cultivar (type III). This shows that type I cultivars are efficient in the use of natural resources, as they are capable of a dry matter yield similar to type III cultivars (Table 1), with a shorter time in the field (Figure 2). Thus, the type I cultivars could save water in irrigated systems, in addition to being less subject to possible attacks from insects and diseases, as well as to competition from weeds (Nascente et al. 2016a). In rainfed systems, the flowering of type I cultivars should be planned to occur outside the period when there is a greater probability of dry spells, due to their very short flowering time, if compared to types II and III (Oliveira et al. 2018).

During the V4.5 (plants with 5 trifoliate leaves) stage, only TAA Dama, BRSMG Marte and BRSMG Uai had dry matter values lower than 500 kg ha^{-1}, with a lower dry matter yield than the other cultivars (Table 1), and BRS FC104 had the highest dry matter (816.6 kg ha^{1}). The type III cultivars (TAA Dama and Pérola) with 7 trifoliate leaves (V4.7) already had dry matter values higher than 1,000 kg ha^{-1}. Although the dry matter values of the type I cultivars (BRS FC104 and TAA Gol) did not reach four-digit values, nor those of the type III cultivars, the dry matter values of the type I cultivars were higher than those of the type II. At the flower budding stage (R5), BRS Estilo and BRSMG Marte showed lower dry matter values than the earlier maturity cultivars. In terms of development, type I and II cultivars attained 7 trifoliate leaves at 33 days after sowing, while type III (TAA Dama and Pérola) only reached this stage at 37 days (Figure 2). Moreover, at 37 days, types I (BRS FC104 and TAA Gol) and II (BRS Estilo and BRS Marte) had already reached the reproductive stage (R5). This same stage was reached by type III only after 42 days. This earlier entry into pre-flowering, when the greatest water demand begins (Oliveira et al. 2018), may provide these cultivars with a greater probability of escaping possible dry spells (Nascente & Melo 2015, Nascente et al. 2016a).

The average grain yield was 2,652 kg ha^{-1}, and the BRS Estilo, BRS FC104 and TAA Gol cultivars had average yields below 2,200 kg ha^{-1}. TAA Dama showed the highest yield in the experiment (3,274.8 kg ha^{-1}). It is important to highlight that the lowest yields, obtained with type I and BRSMG Estilo (type II) cultivars, were still double the national average yield (Conab 2024). Furthermore, type I cultivars closed the cycle 16 days earlier than type III, what is very important for production systems in which common bean is grown in the first crop season and maize is grown as a second crop, as occurs in the south region of the Minas Gerais state (Moreira et al. 2023). These 16 days are of great importance to achieve a higher grain yield in the second crop season, as this can allow the second crop to escape dry spells in phases of greater water demand.

The harvest index is an efficiency parameter representing conversion of acquired nutrients into final yield (Donald & Hamblin 1976, Aráujo & Teixeira 2012); so, modern cultivars, such as those included in the present study, were expected to have high harvest index values. This pattern was not observed in the cultivars evaluated in this study, i.e., the harvest index did not vary with the growth type of the cultivars, and showed an average of 45.9 %. Araújo & Teixeira et al. (2012) reported that, as breeding programs advance, there tends to be an indirect selection of common bean genotypes with higher harvest indices, and that a genotype with a high harvest index does not necessarily have a high grain yield. Among 18 common bean cultivars, Araújo & Teixeira (2003) determined that cultivars belonging to types I, II and III had harvest indices of 55, 58 and 61 %, respectively. However, even though the harvest indices of the cultivars evaluated in the present study were lower than those of the older cultivars studied by Araújo & Teixeira (2003), the average yield of the cultivars in the present study was higher than 2,600 kg ha^{-1}, while the cultivars evaluated by Araújo & Teixeira (2003) had an average yield of 1,130 kg ha^{-1}. The lower yields occurred because the cultivars were grown in soil with high acidity and lower nutrient content than the soil in the present study. Furthermore, most of the cultivars used in the present study naturally have a greater yield potential, as they were released more recently than the cultivars used by Araújo & Teixeira (2003). In the 2000s and 2010s alone, Ribeiro et al. (2024) estimated a genetic gain for grain yield of 1.5 % per year in the South region of Brazil.

The common bean cultivars showed differences in macro- and micronutrient accumulations during the vegetative and reproductive phases (Table 2). The main differences in the vegetative phase were observed when the plants were in the V4 stage. In general, the earlier cultivars (TAA Gol and BRS FC104) accumulated more nutrients than the other cultivars in the stage V4, when the plants had three trifoliate leaves, in accordance with the dry matter accumulation in this stage (Table 1). In the study by Silva & Moreira (2022), a higher initial nutrient accumulation was also observed for the early TAA Gol cultivar, showing the need for studies to define suitable stages for topdressing fertilization for these early common bean cultivars.

In studies carried out in soils with medium to high levels of organic matter, no differences were observed in the yield of very early common bean lines according to the time of nitrogen application (Nascente et al. 2016c, Nascente et al. 2017). However, different soil and climate conditions must be studied, for although the final amounts of accumulated nutrients are similar among the cultivars, type I cultivars accumulate greater amounts of nutrients at the beginning of the vegetative phase (Table 2). So, if there is a nutrient deficiency at that stage, initial development and crop yield may be compromised, because determinate plants practically complete their growth before flowering (Nascente et al. 2016a).

Considering the higher nutrient requirements of the TAA Gol and BRS FC104 cultivars in the early stages of development (Table 2) and their speed in reaching the reproductive stages (Figure 2), i.e., just 37 days (Figure 2), they would probably not be recommended for low fertility soils. Under such conditions, these cultivars would have very little time to acquire nutrients for growth before flowering, when compared to the later cultivars (types II and III), which not only take longer to start flowering, but also continue their growth after the beginning of flowering. In Brazil, the TAA Gol and BRS FC104 cultivars flower at 30 days after emergence and complete their cycles at 70 and 65 days, respectively (Brasil 2022). It is important to note that type I cultivars are determinate; therefore, they show a high vegetative development only until flowering (Oliveira et al. 2018). Thus, the soil must have adequate nutrient availability so as not to limit the initial development of the plants before flowering.

During the V4.5 stage (plants with five trifoliate leaves), the accumulated amounts of N, P, K, Mg, Cu and Fe did not vary among the cultivars. However, the TAA Dama, BRSMG Marte and BRSMG Uai cultivars accumulated less Zn; furthermore, the first two extracted less Ca than the others. Smaller amounts of S and B were accumulated by the TAA Dama, BRSMG Marte, BRSMG Uai and Pérola cultivars. Although there were differences in the accumulation of some nutrients, this would not affect the nutrition and grain yields in practice. This is because there was no difference in the amounts extracted for the nutrients accumulated in larger quantities (N, P and K). Furthermore, under field conditions, these nutrients had already been applied via fertilization (sowing and topdressing) (Araujo et al. 1994, Moreira et al. 2018). In the case of Ca and S, limestone and gypsum applications are made in large quantities to amend the soil (Moreira et al. 2018), which would provide these nutrients in quantities greater than those required by any of the cultivars. In the case of Zn and B, the quantities applied to leaves or on the soil are normally much higher than the demand of cultivars (Araújo & Camelo 2015). Therefore, further studies on these cultivars using different rates of these micronutrients to understand their different enrichment capabilities for human nutrition are suggested.

Table 2. Nutrient accumulation in the vegetative and reproductive stages for different common bean cultivars.

Stage/cultivar		N	P_2O_5	K_2O	Ca	Mg	S	B	Cu	Fe	Mn	Zn
		kg ha^{-1}						ha^{-1}				
3 trifoliate leaves	TAA Dama	15 b*	3 b	14 b	7 b	1.9 b	1.5 b	18 b	3 b	175 a	12 b	13 b
	BRS Estilo	15 b	3 b	15 b	7 b	1.6 b	1.4 b	18 b	3 b	171 a	10 b	13 b
	BRS FC104	24 a	5 a	20 b	11 a	2.4 a	2.2 a	31 a	4 b	160 a	19 a	21 a
	TAA Gol	28 a	6 a	29 a	14 a	3.0 a	2.6 a	34 a	5 a	32 a	30 a	20 a
	BRSMG Marte	10 b	2 b	8 b	4 b	0.9 b	0.8 b	14 b	2 c	102 a	6 b	7 b
	Pérola	19 b	4 b	16 b	8 b	1.9 b	1.6 b	23 b	4 b	293 a	11 b	16 b
	IPR Tuiuiú	18 b	4 b	16 b	9 b	2.1 b	1.8 b	20 b	3 b	222 a	14 b	14 b
	BRSMG Uai	14 b	3 b	12 b	6 b	1.3 b	1.2 b	20 b	2 b	146 a	7 b	10 b
	CV (%)	32	37	30	31	37	34	29	37	26^{+}	27^{+}	37
5 trifoliate leaves	TAA Dama	18 a	4 a	16 a	9 b	1.9 a	1.6 b	20 b	3 a	362 a	11 a	14 b
	BRS Estilo	22 a	5 a	28 a	12 a	2.6 a	2.3 a	28 a	5 a	274 a	19 a	23 a
	BRS FC104	35 a	7 a	31 a	17 a	3.6 a	3.2 a	40 a	6 a	426 a	27 a	30 a
	TAA Gol	28 a	5 a	27 a	13 a	2.6 a	2.5 a	34 a	5 a	338 a	18 a	21 a
	BRSMG Marte	17 a	3 a	19 a	8 b	1.6 a	1.5 b	19 b	3 a	195 a	10 a	14 b
	Pérola	26 a	5 a	25 a	11 a	2.2 a	2.0 b	24 b	4 a	265 a	16 a	20 a
	IPR Tuiuiú	26 a	6 a	30 a	12 a	2.5 a	2.3 a	28 a	5 a	272 a	16 a	22 a
	BRSMG Uai	21 a	4 a	25 a	10 a	1.8 a	1.7 b	25 b	4 a	237 a	15 a	15 b
	CV (%)	16^{+}	30	16^{+}	30	16^{+}	29	15^{+}	31	26^{+}	24^{+}	31
7 trifoliate leaves	TAA Dama	50 a	8 a	50 a	22 a	4.4 a	3.9 a	41 a	9 a	456 a	28 a	38 a
	BRS Estilo	30 b	5 b	33 b	14 b	2.8 b	2.5 b	26 b	5 b	376 a	19 b	23 b
	BRS FC104	41 a	8 a	43 a	19 a	4.4 a	3.8 a	46 a	9 a	554 a	29 a	42 a
	TAA Gol	42 a	8 a	46 a	20 a	3.8 a	3.4 a	42 a	8 a	643 a	33 a	39 a
	BRSMG Marte	23 b	4 b	25 b	10 b	2.1 b	1.9 b	23 b	4 b	354 a	14 b	19 b
	Pérola	51 a	10 a	65 a	24 a	5.66 a	4.6 a	46 a	10 a	435 a	34 a	49 a
	IPR Tuiuiú	23 b	5 b	22 b	11 b	2.1 b	1.9 b	24 b	4 b	325 a	11 b	16 b
	BRSMG Uai	19 b	4 b	23 b	10 b	1.7 b	1.6 b	21 b	4 b	395 a	13 b	17 b
	CV (%)	32	32	33	33	37	32	32	30	25^{+}	37	32
Flower budding	TAA Dama	79 a	16 a	82 b	34 a	8.2 a	6.5 a	73 a	16 a	887 a	41 a	83 a
	BRS Estilo	29 c	5 c	31 d	11 d	2.7 c	2.2 c	32 c	5 c	267 b	17 b	19 b
	BRS FC104	55 b	10 b	55 c	22 c	5.1 b	4.1 b	59 b	9 b	425 b	31 b	42 b
	TAA Gol	55 b	10 b	58 c	21 c	5.1 b	4.2 b	62 b	10 b	931 a	30 b	42 b
	BRSMG Marte	39 c	7 c	45 d	16 d	3.5 c	3.0 c	45 c	7 b	414 b	25 b	34 b
	Pérola	79 a	16 a	99 a	35 a	8.4 a	6.7 a	93 a	16 a	824 a	51 a	69 a
	IPR Tuiuiú	69 a	15 a	100 a	28 b	7.1 a	5.8 a	79 a	15 a	723 a	40 a	54 a
	BRSMG Uai	72 a	15 a	111 a	29 b	7.1 a	5.7 a	87 a	16 a	777 a	44 a	62 a
	CV (%)	20	18	17	17	19	17	16	16	26	30	30
Pod formation	TAA Dama	86 a	24 a	125 a	59 a	13 a	10 a	136 a	29 a	1,084 a	61 a	91 b
	BRS Estilo	102 a	27 a	170 a	67 a	14 a	11 a	150 a	36 a	1,670 a	76 a	123 a
	BRS FC104	132 a	34 a	153 a	82 a	17 a	14 a	199 a	40 a	1,335 a	89 a	143 a
	TAA Gol	113 a	35 a	168 a	76 a	16 a	13 a	206 b	42 a	2,005 a	89 a	137 a
	BRSMG Marte	79 a	24 a	132 a	53 a	11 a	9 a	129 a	28 a	847 a	54 a	93 b
	Pérola	101 a	31 a	165 a	68 a	15 a	12 a	157 a	40 a	1,839 a	86 a	129 a
	IPR Tuiuiú	67 a	21 a	121 a	60 a	12 a	9 a	126 a	28 a	1,155 a	64 a	75 b
	BRSMG Uai	89 a	28 a	177 a	73 a	14 a	11 a	165 a	34 a	1,432 a	72 a	104 b
	CV (%)	13^{+}	24	22	28	25	24	20	23	21+	25	22
Pod filling	TAA Dama	93 a	18 a	97 a	46 a	10 a	8 a	99 a	22 a	676 a	46 a	77 a
	BRS Estilo	125 a	28 a	139 a	70 a	15 a	12 a	171 a	31 a	1,077 a	94 a	129 a
	BRS FC104	140 a	31 a	147 a	66 a	16 a	12 a	172 a	30 a	991 a	90 a	131 a
	TAA Gol	150 a	37 a	153 a	77 a	20 a	15 a	215 a	36 a	1,473 a	115 a	134 a
	BRSMG Marte	123 a	29 a	155 a	66 a	15 a	11 a	148 a	31 a	949 a	81 a	112 a
	Pérola	105 a	24 a	122 a	53 a	12 a	10 a	134 a	25 a	635 a	75 a	91 a
	IPR Tuiuiú	99 a	22 a	116 a	54 a	13 a	9 a	127 a	26 a	811 a	55 a	77 a
	BRSMG Uai	95 a	22 a	126 a	50 a	11 a	8 a	133 a	20 a	570 a	50 a	69 a
	CV (%)	15^{+}	14^{+}	29	30	16^{+}	15^{+}	14^{+}	14^{+}	20^{+}	20^{+}	16^{+}
Physiological maturation	TAA Dama	218 a	61 a	246 a	124 a	39 a	27 a	312 a	39 a	3,622 a	145 a	286 a
	BRS Estilo	165 a	48 a	227 a	87 a	29 a	21 a	288 a	31 a	4,642 a	178 a	233 a
	BRS FC104	160 a	45 a	176 a	80 a	24 a	18 a	233 a	30 a	1,892 a	121 a	203 a
	TAA Gol	167 a	46 a	221 a	104 a	29 a	22 a	282 a	32 a	2,715 a	196 a	225 a
	BRSMG Marte	186 a	56 a	223 a	79 a	25 a	20 a	222 a	28 a	1,251 a	115 a	245 a
	Pérola	157 a	45 a	201 a	67 a	26 a	19 a	254 a	29 a	1,691 a	88 a	185 a
	IPR Tuiuiú	206 a	58 a	223 a	99 a	31 a	24 a	314 a	36 a	3,219 a	153 a	303 a
	BRSMG Uai	178 a	56 a	195 a	77 a	22 a	17 a	240 a	27 a	2,285 a	127 a	198 a
	CV (%)	23	22	30	43	35	32	34	29	47	35	33

* Means followed by the same letter in the column do not differ from each other according to the Scott-Knott test at 5 % of significance. $^{+}$Transformed data; CV: coefficient of variation.

Considering the plants in the V4.7 stage (with 7 trifoliate leaves), the types III (TAA Dama and Pérola) and I (TAA Gol and BRS FC104) cultivars accumulated a larger amount of nutrients than the other cultivars, except for Fe. Up to that stage, BRSMG Uai accumulated only 19.4 kg ha^{-1} of N, while the Pérola cultivar accumulated 50.9 kg ha^{-1} of N, approximately 162 % more than that accumulated by BRSMG Uai. However, it cannot be said that, in nutritional terms, BRSMG Uai is more efficient in the use of N than Pérola, since, from the R5 stage onwards, they show a similar N accumulation. In the flower budding phase (R5 stage), the type II cultivars (BRS Estilo and BRSMG Marte) had lower accumulations of N, P, K, Ca, Mg, S and B than the other ones (Table 2), coinciding with the lower dry matter accumulations in these cultivars (Table 1). From R7 to R9, the maximum rate of dry matter accumulation occurred in the entire plant (Table 1; Silva & Moreira 2022), and there was no difference in the accumulated amounts of nutrients among the cultivars, except for Zn, which had a higher accumulation in the BRS Estilo, BRS FC104, TAA Gol and Pérola cultivars than in the other cultivars. Among the macronutrients, K was most required by the common bean plants, and, among the micronutrients, Fe had the highest accumulation. There was a linear increase in macronutrient and micronutrient accumulations in the common bean plants throughout the cycle (data not shown).

Although there were differences in grain yield among the cultivars (Table 1), in general, the nutrient exports per hectare (data not shown) or per ton of grain (Table 3) were similar. In the case of the quantities of nutrients exported per hectare, the only exception was for potassium, which was exported in smaller quantities (kg ha^{-1} of K_2O) by BRS Estilo (35), BRS FC104 (36) and TAA Gol (37), when compared to Pérola (44), TAA Dama (52), BRSMG Uai (49), IPR Tuiuiú (56) and BRSMG Marte (54). The amounts of K exported in the grain represented just over 20 % of the K extracted from the soil (Table 2), what means that most of the K returned to the soil to be recycled by the crop succeeding common bean. The average nutrient export rates (in kg ha^{-1}) by cultivars in a descending order were: N (87.5) > K_2O (45.3) > P_2O_5 (29) > S (6.1) > Mg (5.9) > Ca (5.2). Regarding the micronutrients, the decreasing order of average export rates (in kg ha^{-1}) was Fe (224) > Zn (91) > B (40) > Mn (34) > Cu (10).

The macronutrient exports per ton of grain were similar among cultivars (Table 3), as also reported by Zanão Júnior et al. (2018). The only exception was Mg, which was exported in smaller quantities by BRSMG Marte (1.8 kg Mg^{-1}). The exported amounts, on average, were 33 kg of N, 11 kg of P_2O_5, 17 kg of K_2O, 1.5 kg of Ca, 2.2 kg of Mg and 2.3 kg of S Mg^{-1} of grain. The average amounts of micronutrients exported per ton of grain were 14 g of B, 3.7 g of Cu, 70 g of Fe, 13 g of Mn and 34 g of Zn. Common bean genotypes with higher dry matter yield generally have a higher nutrient extraction (Westermann et al. 2011, Kachinski et al. 2020). The amounts of nutrients exported by the cultivars in the present study were larger than those exported by the genotypes studied by Westermann et al. (2011). Differences in the amounts of exported nutrients occurred because the cultivars in the current

Table 3. Amounts of macro- and micronutrients exported from every ton of grain produced by different common bean cultivars.

Cultivar	N	P_2O_5	K_2O	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	kg Mg^{-1}						g Mg^{-1}				
TAA Dama	30 a*	10 a	16 a	1.4 a	2.5 a	2.4 a	16 a	3.5 a	82 a	11 a	32 a
BRS Estilo	32 a	11 a	17 a	1.0 a	2.4 a	2.4 a	17 a	3.4 a	64 a	14 a	36 a
BRS FC 104	35 a	12 a	17 a	0.9 a	1.9 a	2.1 a	14 a	3.6 a	66 a	14 a	35 a
TAA Gol	34 a	11 a	17 a	1.5 a	2.2 a	2.3 a	15 a	3.3 a	65 a	13 a	32 a
BRSMG Marte	35 a	12 a	18 a	1.3 a	1.8 b	2.1 a	12 a	3.7 a	70 a	13 a	40 a
Pérola	32 a	10 a	16 a	2.4 a	2.5 a	2.5 a	16 a	3.9 a	72 a	11 a	31 a
IPR Tuiuiú	34 a	11 a	17 a	2.0 a	2.2 a	2.2 a	16 a	4.3 a	68 a	13 a	33 a
BRSMG Uai	35 a	13 a	18 a	1.4 a	2.1 a	2.1 a	16 a	4.0 a	70 a	15 a	36 a
Mean	33	11	17	1.5	2.2	2.3	14	3.7	70	13	34
CV (%)	8.7	13.8	8.3	23.2^{+}	9.7	5.7	15.1	23.8	13.3	15.5	10.7

* Means followed by the same letter in the column do not differ from each other according to the Scott-Knott test at 5 % of significance. $^{+}$ Transformed data; CV: coefficient of variation.

study yielded approximately twice as much as the cultivars used in that study. Furthermore, part of the differences may be linked to genetic variability among the cultivars used (Bulyaba et al. 2020, Mukankusi et al. 2020). There is evidence that current cultivars may have a greater need for nutrients than previous cultivars (Kachinski et al. 2020); thus, it is believed that new nutrient export extraction studies should be developed as new cultivars are released.

CONCLUSIONS

1. The early type I TAA Gol and BRS FC104 cultivars showed a greater accumulation of dry matter and nutrients than the indeterminate cultivars (types II and III) at the beginning of development (V4 stage);
2. From the R7 to R9 stage, there were generally no differences in nutrient extraction by cultivars, or in the harvest index;
3. The amounts of nutrients exported per hectare or per ton of grain produced, as well as the harvest index, were similar among the cultivars;
4. The average nutrient export rates (kg ha^{-1}) by the cultivars, in a descending order, were N (87.5) > K_2O (45.3) > P_2O_5 (29) > S (6.1) > Mg (5.9) > Ca (5.2). For micronutrients, the average export rates (g ha^{-1}), in a decreasing order, were Fe (224) > Zn (91) > B (40) > Mn (34) > Cu (10);
5. The BRS Estilo, BRS FC104 and TAA Gol cultivars had average yields below 2,200 kg ha^{-1}, and TAA Dama had the highest yield (3,274.8 kg ha^{-1}).

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