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# Tuber yield and quality of potato processing cultivars submitted to nitrogen rates

**Cleto Tamanini Junior [1]; Leonardo Z Anderle [1]; Lucas B de Souza [1]; Leonardo Balena [2]; João Pedro Malanchuk [1]; Cinthia K de Matos [1]; Jackson Kawakami [1]**

[1]Universidade Estadual do Centro Oeste do Paraná (UNICENTRO), Guarapuava-PR, Brasil. [2]Escola Superior de Agricultura Luiz de Queiroz (ESALQ), Piracicaba-SP, Brasil; jkawakami@unicentro.br

## ABSTRACT

Consumption of processed potatoes is increasing in Brazil. However, little information is available on the effect of nitrogen (N) rates on performance of potato cultivars developed in Brazil. The objective of this work was to evaluate yield and quality of tubers of potato processing cultivars, submitted to N rates at planting. Three field trials with eight treatments were conducted: two cultivars (Atlantic and BRSIPR Bel) and four N rates (0, 75, 150, and 225 kg/ha). Yield and quality of tubers were evaluated, as well as the post-frying absorbed oil content. Cultivar BRSIPR Bel showed higher total tuber yield (18% more) and commercial tuber yield (15% more) due to the production of higher number of tubers (29% more) compared to the cultivar Atlantic. On the other hand, Atlantic cultivar produced tubers with higher dry weight (22%) and lower oil absorption (38%). For both cultivars, the estimated N rate of 151 kg/ha resulted in the highest commercial tuber yield (diameter larger than 45 mm): 34.0 t/ha. For all studied variables there was no interaction between cultivar and N rate, concluding that the cultivars in this study (American and Brazilian origin) respond similarly to N rates.

**Keywords:** *Solanum tuberosum*, Atlantic, BRSIPR Bel, fertilizing, fried potato, variety.

## RESUMO

**Produtividade e qualidade de tubérculo de cultivares de batata indústria submetidas a doses de nitrogênio**

O consumo de batata industrializada está aumentando no Brasil. Entretanto, há pouca informação sobre o efeito de doses de nitrogênio (N) no desempenho de cultivares de batata estrangeira e brasileira. O objetivo do trabalho foi avaliar a produtividade e a qualidade de tubérculos de cultivares de batata destinada ao processamento industrial submetidas a doses de N no plantio. Foram conduzidos experimentos a campo por 3 anos com oito tratamentos: duas cultivares (Atlantic, EUA e BRSIPR Bel, Brasil) e quatro doses de N (0, 75, 150 e 225 kg/ha). Foram avaliadas a produtividade e a qualidade dos tubérculos, além do teor de óleo absorvido. A cultivar BRSIPR Bel apresentou maior produtividade total (18% a mais) e de tubérculos comerciais (15% a mais) devido à produção de maior número de tubérculos (29% a mais) em relação à cultivar Atlantic. Por outro lado, a cultivar Atlantic produziu tubérculos com maior porcentagem de massa seca (22%) e menor absorção de óleo (38%). Para ambas as cultivares, a dose estimada de N de 151 kg/ha foi a que proporcionou a maior produtividade comercial (diâmetro maior que 45 mm): 34,0 t/ha. Para todas as variáveis estudadas não houve interação entre cultivar e dose de N, concluindo-se que as cultivares do presente trabalho (de origem americana e brasileira) respondem de maneira análoga às doses de N.

**Palavras-chave:** *Solanum tuberosum*, adubação, Atlantic, batata frita, BRSIPR Bel, variedade.

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Potato (*Solanum tuberosum*) is worldwide an important food due to its nutritional compounds, on average 109 kcal, 18 g carbohydrates, 2.3 g protein, 150 to 1386 mg potassium, 42 to 120 mg phosphorus, and 14 mg vitamin C per 100 g of peeled cooked potato (Burgos *et al.*, 2020). In addition, potato is a staple food in several countries (Burgos *et al.*, 2020).

With an increasing demand for greater convenience in food preparation, the trend for several foods is to increase their industrialization, as processed foods have a more practical and faster preparation (Silva *et al.*, 2016). The global potato chips market reached $32.2 billions in 2021 and the market is estimated to reach $39 billions by 2027 (IMARC, 2022). In Brazil, the industrialized potato sector makes up 39% of the overall market (Deleo *et al.*, 2018). Of this segment, 21% is still reliant on imports, primarily in the form of pre-fried products, while the remaining 18% is produced domestically and includes pre-fried items as well as chips (Deleo *et al.*, 2018).

The most planted potato cultivars for the industry are imported: Asterix, of Dutch origin, the main cultivar to produce French fries, and Atlantic, of USA origin, which is the main cultivar in Brazil and worldwide to produce chips and crisps (Evangelista *et al.*, 2011). Cultivars intended for

industrial processing produce tubers with characteristics that allow to obtain a final product with good quality. Some examples are high dry weight and low reducing sugars content (Silva *et al.*, 2018).

The better the characteristics of the cultivar, the better the quality of the final product and the lower the production cost, because the higher the dry weight content of the tuber produced, the lower the absorption of oil, providing a higher frying yield (Araújo *et al.*, 2016). It is important to study the different cultivars that are specific for this purpose, and test if fertilizer management affects production and quality (Wang *et al.*, 2020).

Nitrogen (N) is the main macronutrient required and absorbed by potato plants (Fernandes *et al*., 2011). Its application can directly affect tuber growth, yield, and quality (Souza *et al*., 2019). Potato cultivars can take up different amounts of N and respond differently to N fertilizers (Reiter *et al*., 2012). It is necessary to evaluate the characteristics and N requirements of each cultivar and appropriately adjust the rates of N fertilizer (Assunção *et al.*, 2021).

Nitrogen rates affected the dry weight content of the cultivar Asterix (ranging from 18.4% to 20.8%) (Oliveira *et al*., 2006). Another study with cultivar Agata observed that N rates affected the tuber dry weight percentage and when N was supplied in full rate at planting, the plants had higher leaf area index and dry weight of tubers (Kawakami, 2015).

In these studies, variations in fertilization were evaluated in foreign cultivars, but fertilization may affect Brazilian cultivars differently. The management of N fertilization for Brazilian cultivars may not be the same as that adopted for imported cultivars, due to their different origins. In addition, optimum N rate for potato fertilization varies around the world (Reiter *et al*., 2012), suggesting different cultivar response to N.

There exist little information about national processing cultivars with different fertilizer rates. The objective of this work was to evaluate the tuber yield and quality response of processing potato cultivars subjected to N rates.

## MATERIAL AND METHODS

Three experiments were conducted on commercial potato fields of a local grower, all located in Guarapuava-PR (25ºS, 52ºW, altitude 996 m). The soil in all fields is very clayey Typic Hapludox (United States Department of Agriculture) (USDA, 1999). Black oats were planted in the winter and soybeans or corn in the summer. The climate is classified as Cfb (Köppen, high altitude temperate) (IAPAR, 2000). Average temperature and rainfall data were obtained from the meteorological station located about 10 km from the experimental site (Figure 1).

The periods of the researches were from December 2015 to April 2016 (2016), from January to May 2017 (2017), and from December 2017 to April 2018 (2018). In each research there were eight treatments: two cultivars (Atlantic and BRSIPR Bel), four N rates at planting (0, 75, 150, and 225 kg/ha), and four replications (blocks). These rates represent 0, 47, 94 and 141% of the recommended dose by the Fertilization and Liming Manual for the State of Parana (SBCS/NEPAR, 2017). The experimental design of randomized blocks in a factorial scheme was adopted: 2 cultivars (Atlantic and BRSIPR Bel), 4 N rates (0, 75, 150, and 225 kg/ha) and 3 years (2016, 2017 and 2018).

Soil chemical analysis was performed in all three years (0-20 cm), in which the following values were found for 2016, 2017 and 2018, respectively: pH ($CaCl_2$): 4.7; 4.1 and 5.1; P available ($mg/dm^3$): 5.62; 3.76 and 2.40; exchangeable K ($cmol_c/dm^3$): 0.48; 0.5 and 0.60; exchangeable Ca ($cmol_c/dm^3$): 3.22; 2.18 and 3.99; exchangeable Mg ($cmol_c/dm^3$): 1.39; 0.89 and 1.35; Organic matter (%): 4.17; 3.61 and 4.05 and base saturation (V%): 47.8; 26.4 and 57.6. For liming, a target saturation of 60% was adopted (SBCS/NEPAR, 2017), and calcitic limestone was used.

The soil was previously prepared by plowing, harrowing, and chisel plowing. Type III seed tubers (30-40 mm diameter) were used as planting material for Atlantic, provided by a certified producer, and BRSIPR Bel, provided by the Embrapa Experimental Station in Canoinhas-SC, and by the "União Castrense Ltda" agricultural cooperative (Unicastro). Tubers were planted at 0.80 m between rows and 0.25 m between plants (50,000 plants/ha), with one outer border line, and at least one plant at the beginning and end of the lines. In 2016 and 2017, each experimental plot had 6 rows with 7 plants per row with a plot size of 4.8 m by 1.75 m (8.4 $m^2$). In 2018 each plot consisted of 6 rows with 15 plants per row with a plot size of 4.8 m by 3.75 m (18 $m^2$).

Nitrogen was supplied in the form of urea (45% N) in all experiments. Fertilization with phosphorus and potassium followed the standard adopted by local growers: 560 kg/ha of $P_2O_5$ (single super phosphate) and 320 kg/ha of $K_2O$ (potassium chloride). These rates of $P_2O_5$ and $K_2O$ are above the rate recommended by the Fertilization and Liming Manual for the State of Parana (SBCS/NEPAR, 2017). All fertilizers were applied in full rate on the day of planting, directly in the furrow.

Hilling was performed around 28 days after planting (DAP). Both planting and hilling were done manually. The phytosanitary management (weeds, pests, and diseases) adopted was the same as that used by the grower.

Plants were harvested after physiological maturity, about 120 DAP. For the years 2016 and 2017, tubers were manually collected from 10 plants per plot, and in the year 2018, from 12 plants per plot. The collected tubers were taken from central plants of the plot.

Morphological variables were assessed from 4 plants per plot, in 2018 only: number of main stems, number of secondary stems, leaf area index (LAI), number and fresh weight of tubers. To estimate LAI, leaf sample (2,000 $cm^2$) of 4 plants in each plot was measured using leaf area meter (LI3100C, Li-Cor USA). This leaf sample and the rest of the leaves of the 4 plants were dried (70°C). To estimate the total leaf area of the 4 plants and the LAI, the following

equation was used:

LAI= [(Sample leaf area x Total leaf dry weight / Sample leaf dry weight)/10,000] x 5 / 4

Tubers were washed and, after drying, the yield (number and weight) of total and commercial tubers were assessed. Commercial tubers were defined as those with a diameter larger than 45 mm. The dry weight percentage of tubers was estimated by taking 250 to 300 g samples of slices from several tubers, which were placed in a forced air heater for drying at 70ºC until reaching constant weight. After drying, the slices were weighed and with the fresh and dry weight of the sample the dry weight percentage was calculated.

To calculate the percentage of oil absorption by the chips, the following equation was used:

Y=59,10894-(0,96768*X)

Where Y = percentage of oil absorbed by the chips and X = percentage of tuber dry weight (Gould, 1999).

Data were subjected to homogeneity (Shapiro Wilk) and variance and regression (linear and quadratic) analysis using the SISVAR statistical package. A joint analysis of the three experiments was performed (Moore & Dixon, 2015). For some variables there were not significant effects in anova but they were analyzed via polynomial regressions (Finkelman *et al*., 1977). When regression was significant, the one with the highest coefficient of determination ($R^2$) was chosen. Non-normal data (total yield, commercial yield, tuber dry mass percentage and oil content) were transformed ($\sqrt{x+0.5}$).

## RESULTS AND DISCUSSION

The temperature in 2018 was lower from the 1st to the 60th DAP, whereas from the 61st to the 120th DAP, the lowest temperatures were observed in 2017 (Figure 1). We observed that from the 46th to the 105th DAP, 2017, occurred the lowest rainfall, especially between the 61st to the 75th DAP, the period in which rainfall was only 1.5 mm. In total, 717, 441, and 557 mm of total precipitation was recorded during the crop cycle in 2016, 2017, and 2018, respectively.

None of the assessed variables

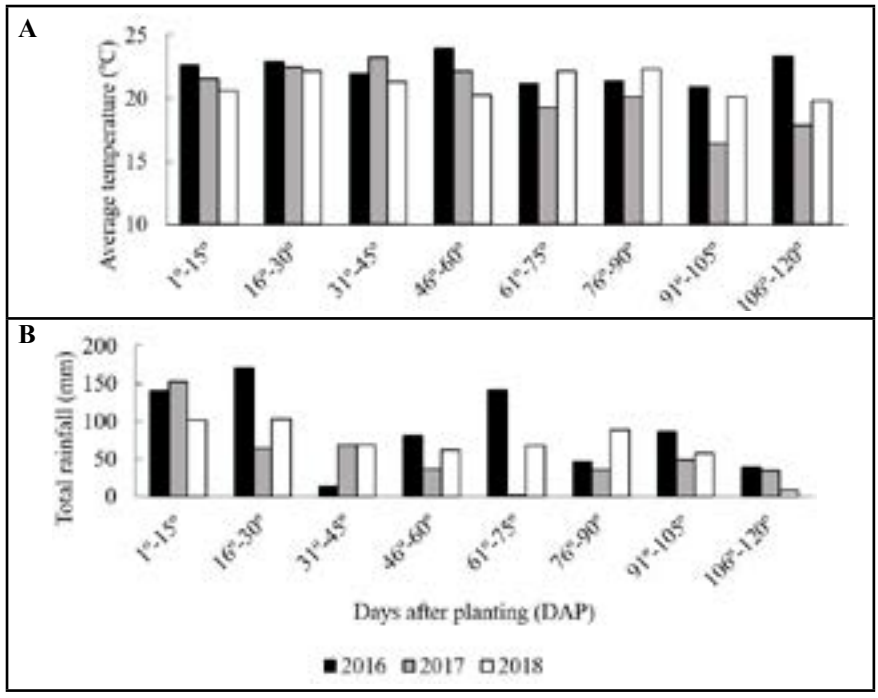


**Figure 1.** Data for average temperature (ºC) (A) and rainfall (mm) (B), during the experiments in the years of 2016, 2017 and 2018. Source: SIMEPAR weather station, campus Cedeteg. Guarapuava, UNICENTRO, 2022.

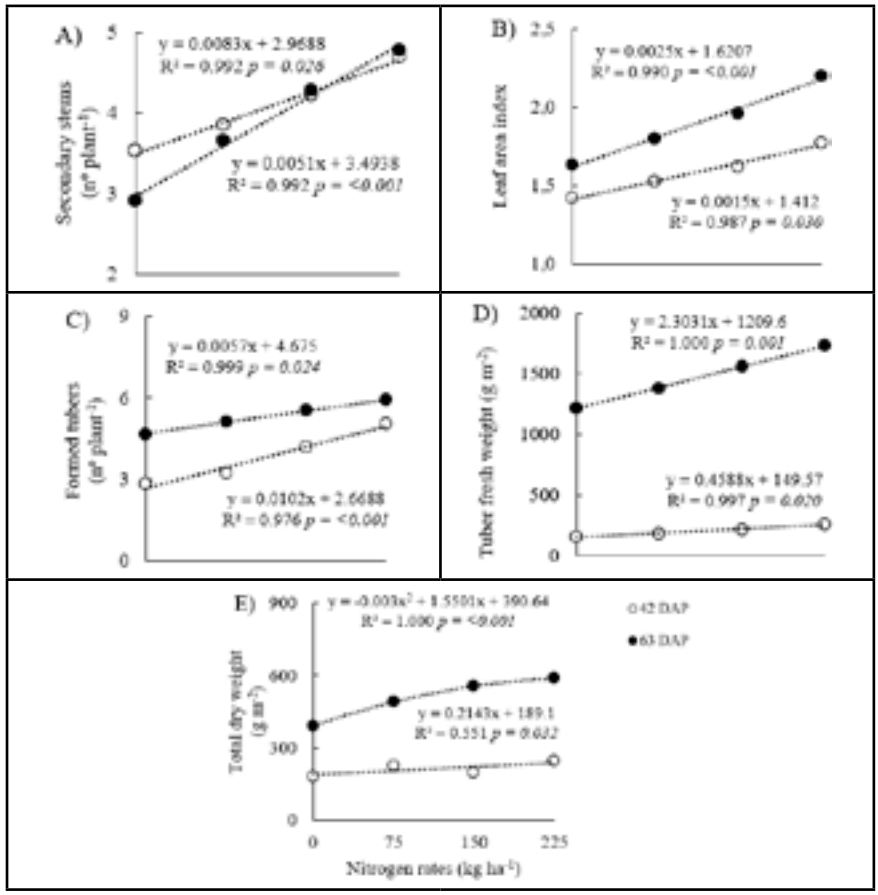


**Figure 2.** Number of secondary stems per plant (A), leaf area index (B), number of tubers (C), fresh weight of tubers (D) and total dry weight (E) in plants of two potato cultivars submitted to four nitrogen rates at 42 and 63 DAP, in 2018. Guarapuava, UNICENTRO, 2022.

**Table 1.** Significance level for the quantified variables and regression analysis in plants of two potato cultivars submitted to four nitrogen rates. Guarapuava, UNICENTRO, 2022.

| Variable | DAP[1] | Year (Y) | Cultivar (C) | Rate (R) | YxC | YxR | CxR | YxCxR | Reg. | VC (%) |
|---|---|---|---|---|---|---|---|---|---|---|
| SS[2] | 42 | - | ** | ns | - | - | ns | - | L** | 21.0 |
| | 63 | - | ** | ** | - | - | ns | - | L** | 17.6 |
| LAI[2] | 42 | - | * | ns | - | - | ns | - | L* | 20.1 |
| | 63 | - | ** | ** | - | - | ns | - | L** | 3.14 |
| NT[2] | 42 | - | ** | ** | - | - | ns | - | L** | 23.9 |
| | 63 | - | ** | ns | - | - | ns | - | L* | 18.6 |
| FWT[2] | 42 | - | ** | ** | - | - | ns | - | L** | 22.6 |
| | 63 | - | ** | ** | - | - | ns | - | L** | 11.4 |
| TDW[2] | 42 | - | ** | * | - | - | ns | - | L* | 16.9 |
| | 63 | - | ** | ** | - | - | ns | - | Q** | 9.00 |
| TY | - | ** | ** | ** | ns | ns | ns | ns | Q** | 6.26 |
| CY | - | ** | ** | ** | * | ns | ns | ns | Q** | 6.97 |
| NTT | - | ns | ** | ** | ** | ns | ns | ns | Q** | 13.5 |
| NCT | - | ** | ** | ** | * | ns | ns | ns | Q** | 14.0 |
| DW | - | ** | ** | ns | ** | ** | ns | ns | ns | 2.46 |
| AO | - | ** | ** | ns | ** | ** | ns | ns | ns | 1.30 |

[1]DAP= Days after planting; SS= Secondary stems; LAI= Leaf area index; NT= Number of tubers; FWT= Fresh weight of tubers; TDW= Total dry weight; TY= Total yield; CY= Commercial yield; NTT= Number of total tubers; NCT= Number of commercial tubers; DW= Dry weight percentage and AO= Oil absorption. [2]= data available only in 2018 season; ns = not significant; * = $p<0.05$ and ** = $p<0.01$. L= Linear regression; Q= Quadratic regression. VC= Variation coefficient.

showed a three-way interaction among year x cultivar x rate (YxCxR) (Table 1). Similarly, none of the variables showed an interaction between cultivar x N rate (CxR). This result rules out the hypothesis that the studied cultivars due to their different origins respond differently in yield to different N rates, that is, the USA cultivar (Atlantic) and the Brazilian cultivar (BRSIPR Bel) respond in a similar manner to rates of N between 0 and 225 kg/ha.

For the morphological variables, an effect of cultivar was observed in all variables. There was an increase in the number of secondary stems in the plants according to the increase in the N rate, both at 42 and 63 DAP (Figure 2A). This increase was also observed for leaf area index (LAI, Figure 2B), the number of formed tubers (Figure 2C) and fresh tuber weight (Figure 2D). Nitrogen is an important element for plant development, and, when in low quantities, it inhibits plant growth (Taiz *et al*., 2017). Except the number of formed tubers, in every other assessed morphological variables the effect of N rate was greater at 63 DAP than at 42 DAP (higher angular coefficient of the regression at 63 DAP). This result corroborates the information that the effect of increasing N rate is more pronounced in the intermediate and final stages (after 54 DAP) compared to the early stages (up to 40 DAP) of potato plant growth (Wen *et al*., 2019). Total plant dry weight showed a similar trend to the other morphological variables at 42 DAP, i.e., it increased with increasing N rates. However, at 63 DAP, the trend was quadratic (Figure 2E).

The year x cultivar interaction (YxC) was significant for all yield variables except for total yield (TY, Table 1). All years differed in total yield, in the descending order of 2018 > 2016 > 2017; the year 2018 resulted in a 40% higher yield than that observed in the year 2017 (Figure 3A). The lower yield observed in 2017 probably occurred because in that year the precipitation from 46 DAP to 105 DAP, as well as the average temperature from 61 DAP, were lower compared to the other years (Figure 1).

The national cultivar BRSIPR Bel showed a higher total yield (36 t/ha) than the control cultivar, Atlantic (30 t/ha) (Figure 3B), corroborating research that reports that this cultivar has a high yield potential (Pereira *et al*., 2015). BRSIPR Bel is a Brazilian cultivar released in 2012 (Pereira *et al*., 2015; Oliveira *et al.*, 2018), selected for the soil and climate conditions of Brazil. 'BRSIPR Bel' formed a higher total tuber number compared to Atlantic, in all three years (data not shown), making this the probably responsible factor for the higher total yield of this cultivar.

Nitrogen rates had a quadratic effect on both total and commercial yield. The estimated rate that resulted in the highest yield was 147.5 and 151.7 kg/ha of N, which resulted in yields of 35.7 and 34.0 t/ha for total and commercial yield, respectively (Figure 3C). The maximum

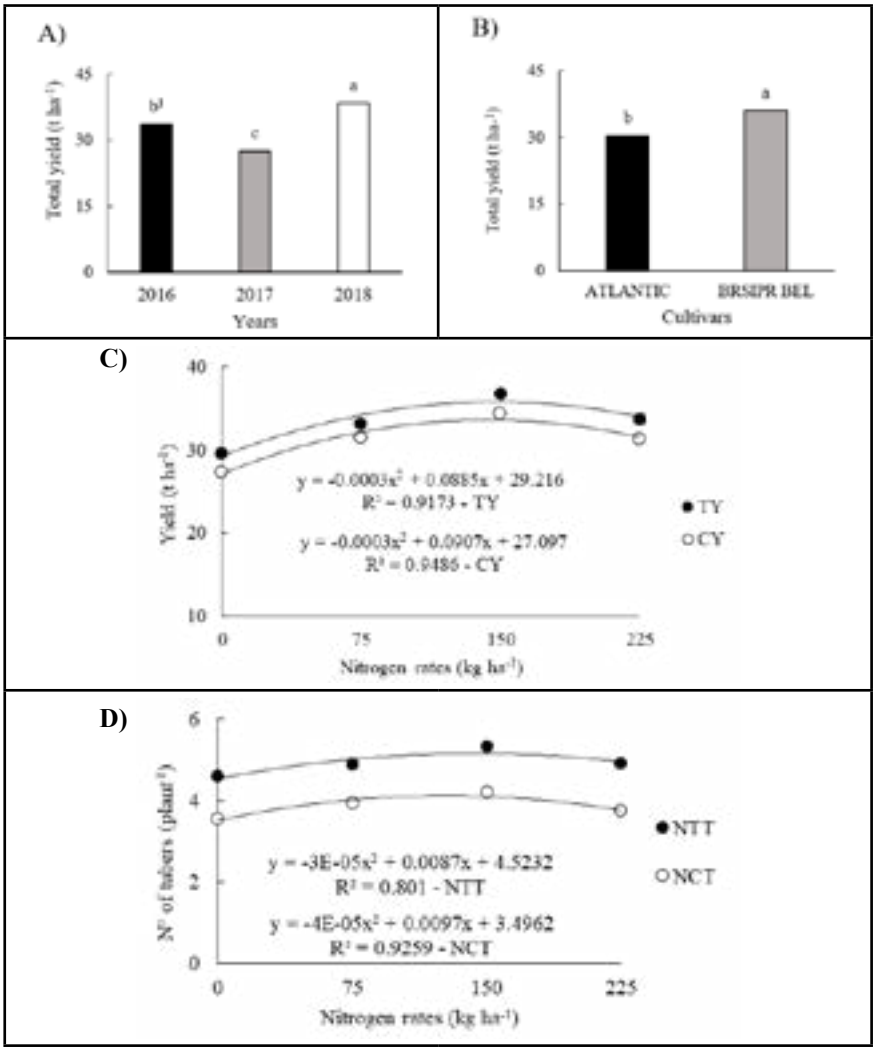


**Figure 3.** Total yield (TY) for each year (A) and cultivars (B), quadratic regression for the total (TY) and commercial (CY) yields (C), and the result of the regression analysis for the number of total (NTT) and commercial (NCT) tubers (D), from plants of two potato cultivars submitted to four rates of nitrogen. [1]Means followed by the same letter do not differ by Tukey's test at 5% probability. ** = p<0.01. * = p<0.05. Guarapuava, UNICENTRO, 2022.

total yield rate observed in the present study is corroborated by other studies that also observed quadratic response of yield to N rates and observed higher yields with 136-160 (Souza *et al*., 2019), 168 (Zaeen *et al*., 2020) and 224 kg/ha of N (Makani *et al*., 2020).

Regarding the YxC interaction, in 2017 the cultivars did not differ in commercial yield, and in the other two years, the cultivar BRSIPR Bel showed higher commercial yield (2016 and 2018: 35.9 and 38.9 t/ha, respectively). Atlantic had higher total tuber number in 2018 (4.8 tubers/plant) compared to the other years (2016 and 2017: 4.2 and 3.9 tubers/plant, respectively), whereas BRSIPR Bel did not differ between years (2016, 2017 and 2018: 5.6; 5.8 and 5.3 tubers/plant, respectively). In two years, BRSIPR Bel showed a higher number of commercial tubers (2016 and 2017: 4.5 and 3.7 tubers/plant, respectively), however, in 2018 the cultivars Atlantic (4.2 tubers/plant) and BRSIPR Bel (4.5 tubers/plant) did not differ in this variable. The year 2017 was when the cultivars produced the least number of commercial tubers, and this fact is probably responsible for the lower commercial yield observed in that year. Nitrogen rates influenced total and commercial tuber number (Figure 3D). The effect was quadratic and the estimated N rates that resulted in the highest total (5.15 tubers/plant) and commercial (4.08 tubers/plant) tuber numbers were 145.0 kg/ha of N and 121.3 kg/ha of N, respectively.

The variables related to processing quality (tuber dry weight, DW, and oil absorption, OA) showed no three-way interaction or cultivar x rate (CxR) interaction, as well as no N rate effect was observed on these variables (Table 1). The cultivars differed in all years, with Atlantic producing tubers with a dry weight percentage on average 2% higher than BRSIPR Bel. The percentage of dry weight is a quality parameter of potatoes for frying, the higher this content, the less oil is absorbed during the frying process. Atlantic absorbed on average 2% less oil than BRSIPR Bel. Nitrogen rates did not affect the percentage of dry weight in the years 2016 and 2017, but in 2018 the rate that resulted in higher percentage of dry weight and lower oil absorption was of 127.73 kg/ha of N.

In conclusion, the two studied cultivars, Atlantic (USA cultivar) and BRSIPR Bel (Brazilian cultivar), responded similarly to N rates in relation to yield components. BRSIPR Bel showed higher total and commercial yields because it had a greater number of tubers. Atlantic produced tubers with a higher percentage of dry weight and lower oil absorption, i.e., better industrial quality.

The estimated N rate of 151.2 kg/ha resulted in the highest commercial yield: 34.0 t/ha, for both cultivars.

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