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Growth, tuber yield and quality of potato clones and cultivars

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ABSTRACT

This study aimed to evaluate the plant performance of two advanced potato clones compared to two standard cultivars. Field experiments were carried out in Canoinhas-SC, Pelotas-RS and Brasília-DF. The experimental design was in randomized blocks with four replications of plots composed of 44 useful plants plus borders. Four plant samples per plot were collect 30, 44, 56, 72, 86 and 100 days after planting. Morpho-agronomic characters were evaluated throughout the crop cycle, and at the end of the crop cycle tuber yield and frying quality were determined. There was a direct relationship between tuber yield and shoot development. For these characters, both clones F63-10-07 and F21-07-09 presented superior values compared to the standard cultivars in Pelotas, and these together with 'Atlantic' were superior to 'Asterix' in Canoinhas. In Brasilia, the standard cultivars showed greater shoot development, but the final marketable yield was not statistically different. F63-10-07 and 'Atlantic' have a lower stem number per plant, indicating the need to manage this character to adjust the stem density in the field.

Keywords: *Solanum tuberosum*, leaf area index, specific gravity, frying color.

RESUMO

Crescimento, produtividade e qualidade de tubérculos de clones e cultivares de batata

O presente estudo objetivou avaliar o desempenho das plantas de dois clones avançados de batata comparativamente a duas cultivares padrões. Os experimentos foram conduzidos em Canoinhas-SC, Pelotas-RS e Brasília-DF. O delineamento experimental foi em blocos casualizados com quatro repetições de parcelas compostas por 44 plantas úteis, além das bordaduras. Coletas destrutivas de quatro plantas por parcela foram realizadas aos 30, 44, 56, 72, 86 e 100 dias após o plantio. Caracteres morfoagronômicos foram avaliados ao longo do ciclo da cultura, e ao final do ciclo a produtividade de tubérculos e a qualidade de fritura foram determinadas. Verificou-se uma relação direta de produção de tubérculos com desenvolvimento da parte aérea das plantas. Quanto a esses caracteres, ambos os clones F63-10-07 e F21-07-09 apresentam valores superiores em comparação às cultivares padrão em Pelotas, e esses, juntamente com 'Atlantic', são superiores à 'Asterix' em Canoinhas. Em Brasília as duas cultivares apresentaram maior desenvolvimento da parte aérea, mas a produção comercial final não foi estatisticamente diferente. F63-10-07 e 'Atlantic' apresentam menor número de hastes por planta, indicando a necessidade de manejo dessa característica para ajustar a densidade de hastes por área.

Palavras-chave: *Solanum tuberosum*, índice de área foliar, peso específico, cor de fritura.

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The potato (*Solanum tuberosum* L.) crop has enormous socio-economic importance, constituting the basis for food security in Brazil. In 2021, production was over 3.8 million tons, in an area of 116 thousand hectares, and average yield of 33 t/ha (IBGE, 2023).

However, foreign cultivars predominate in the country, mainly from Europe and North America. Despite the good tuber appearance and frying quality, potatoes are generally characterized as poorly adapted to Brazilian growing conditions, besides its low resistance to main pests and diseases that occur in the producing regions (Pereira *et al*., 2020). Consequently, to obtain higher yield and good tuber quality, these cultivars require a large amount of inputs (Pereira *et al*., 2020). For this reason, the development of more adapted national cultivars has been demanded by the production sector.

To develop or test a genotype in a given environment, it is important to evaluate its growth dynamics. This analysis consists of measuring, at regular

intervals, the biomass accumulated in different plant organ. So, it is possible to obtain the growth curve for each studied organ and, thus, monitor the development of the plant, including the underground portion (tubers), and the contribution of the different organs to total growth (Pereira *et al*., 2020).

Knowing the development of the plant throughout the vegetative cycle can also help to determine the best plant spacing, the best stages of development to carry out cultural practices, such as hilling, top dressing, the most critical times for phytosanitary and irrigation management, and the best time to desiccate the shoots, specifically for each genotype (Silva *et al*., 2022).

Regarding the development of potato plants, the components of the aboveground portion are characteristics commonly used in plant vigor evaluation, and may be associated to tuber yield, considering that the leaf surface is related to the plants' photosynthetic potential (source), which determines approximately 90% of the biomass allocated to the tubers (drains) (Fernandes *et al*., 2010; Santos *et al*., 2019). Therefore, parameters related to the source-sink relationship are important to be characterized in potato plants.

This study aimed to evaluate the performance of two advanced potato clones compared to two standard cultivars.

MATERIAL AND METHODS

The experiments were conducted in Canoinhas-SC (26°10'S, 50°21'W, 765 m altitude), Pelotas-RS (31°41'S, 52°26'W, 57 m altitude), and Brasília-DF (15º55'S, 48º08'W, 999 m altitude). The climate of these regions, according to Köppen-Geiger, is classified as Cfb, Cfa, and Aw, respectively. The soils are classified as Dystrophic Red Latosol, Red-Yellow Podzolic with clayey and sandy loam textures and Dystrophic Latosol, respectively (Santos *et al*., 2018). Climatological data were obtained from automatic stations installed close to the experiments. The average temperature during the experiments varied between a minimum of 13.3°C and a maximum of 23.9°C in Canoinhas, between 12.7°C and 21.0°C in Pelotas, and between 15.0°C and 26.0°C in Brasília. The accumulated precipitation was 331.4 mm, 646.2 mm, and 20 mm at the three locations, respectively. In Brasília, irrigation was used to maintain field capacity, with approximately 40 mm of water depth per sprinkler, weekly. The planting dates were August 10th, 2021, August 6th, 2021, and May 16, 2021, respectively.

In the three locations, fertilization was carried out with 3,000 kg/ha NPK 04-14-08. Seed tuber size was 40-50 mm in diameter, previously stored for eight months in a cold room at 3.5±0.5ºC. Planting spacing was 35 cm between plants and 75 cm between rows in Canoinhas and Pelotas and 35 cm between plants and 80 cm between rows in Brasília. Hilling was carried out 30 days after planting in the three locations.

The genotypes evaluated are clones in an advanced selection stage. F63-10-07 has red rough skin tubers, oval shape, high dry matter content and good frying quality, obtained from a cross between the cultivar Rioja and the clone C1750-15-95; F21-07-09 has yellow skin, round shape and good frying quality, obtained from a cross between the cultivar White Lady and the clone C1750-15-95. The two clones were compared to the standard cultivars Asterix, which has red and smooth skin, oblong shape, and medium dry matter content, and Atlantic, which has yellow and rough skin tuber, round shape, high dry matter content, and good frying quality. Both cultivars are widely cultivated in the country. The first is a dual purpose, fresh market and french fry processing cultivar, and the second is a chipping and shoestring cultivar. The experimental design was of randomized complete blocks with four replications of plots composed of 60 useful plants, planted in two rows of 30 plants, and borders.

Collections of four plant samples per plot were carried out at 30, 44, 58, 72, 86 and 100 days after planting (DAP), to obtain growth curves, always discarding the first two plants from the two central useful lines. In Pelotas and Brasília, defoliation caused by leafminer larvae (*Liriomyza* spp.) did not make it possible to evaluate the aboveground plant parts 86 DAP. But, in both places, the plants were already in the process of senescence; therefore, the early harvest in both locations did not significantly affect the evaluations. The plants were separated into stems, leaves and tubers. Immediately after collections, still in the field, the leaf fresh mass (LFM, g/plant) was determined, and in the shed, the leaf number (LN, number/plant), stem number (SN, number/plant), length of the longest stem (LLS, cm), and tuber fresh mass (TFM, g/plant). In Canoinhas and Pelotas the leaf area index (LAI) was also evaluated, given by the ratio between the leaf area and the area occupied by the plants. Data were obtained using the leaf disc method (Silva *et al*., 2022). A total of 20 leaf discs were removed with the aid of a perforator with a standard area of 2.02 cm^2, followed by weighing in the laboratory, immediately after collecting the plants in the field to avoid dehydration, and using a precision scale and extrapolation of these values in relation to the leaf fresh mass (LFM).

In the last collection, at 100 DAP in Canoinhas, and at 86 DAP in the other two locations, 20 plants from each plot were harvested to estimate final yield, expressed in total tuber mass (TTM, t/ha), number (TTN, ha/1000), and marketable tuber yield (MTY, t/ha), above 45 mm in diameter. For Canoinhas and Pelotas, the average tuber mass was also calculated, given by the ratio between the TTM and the TTN. After, the specific gravity and frying color were assessed. The specific gravity was assessed on commercial-sized tuber samples of 3629 g using a Snack Food Association hydrometer (Arlington, VA, USA). The frying color was evaluated in chips, using samples of three healthy tubers of marketable size per plot. From each sample, 15 slices, 2.0 mm thickness were obtained, which were fried in vegetable oil at 180°C initial temperature until bubbling ceased. The frying color was visually evaluated, jointly by four people, assigning 1 to 9 scores (1= dark; 9= light) (Silva *et*

al., 2018).

The data were checked regarding the assumptions of normality of residuals using the Lilliefors test and homogeneity of variances using the Bartllet test and then submitted to individual variance analysis. After verifying the difference less than 7 between the largest and smallest mean square of residues, joint analysis was performed using the F test at a 5% significance level. In addition, the data were submitted to regression and simple correlation analyses. The yield averages from the last harvest were grouped using the Scott & Knott test at 5% significance level. All analyzes were performed using the Genes statistical package (Cruz, 2016).

RESULTS AND DISCUSSION

The periods of increase and then decrease in the measurements and growth rates of the aboveground part (leaves and stems), and the corresponding increase in tuber mass, occur due to a natural process in potato plants, in which the photoassimilates produced in the aboveground part are translocated to tubers to be stored mainly as starch. This process starts at the beginning of tuber formation, and tends to accelerate with the development of the crop, gradually decreasing at the end of the growth cycle and end with plant senescence (Fernandes *et al*., 2010).

The leaf number per plant was higher in the cultivar Asterix and lower in the clone F63-10-07, compared to the other two genotypes, mainly in Pelotas (39.85 and 26.62, respectively) and Brasília (42.67 and 24. 73, respectively) (Figure 1 and Box 1). The number of days from planting to obtaining the maximum leaf number was greater in the clone F63-10-07 (average of 69.75 days for the three locations), which was approximately 10 days longer compared to 'Asterix' (59.38 days), and similar to both the cultivar 'Atlantic' (65.89 days) and the clone F21-07-09 (64.87 days). The highest leaf number for 'Asterix' occurred mainly at the beginning of the cycle, but the number tended to rapidly decrease as the vegetative cycle progressed (senescence) (Figure 1 and Box 1). 'Asterix' has the

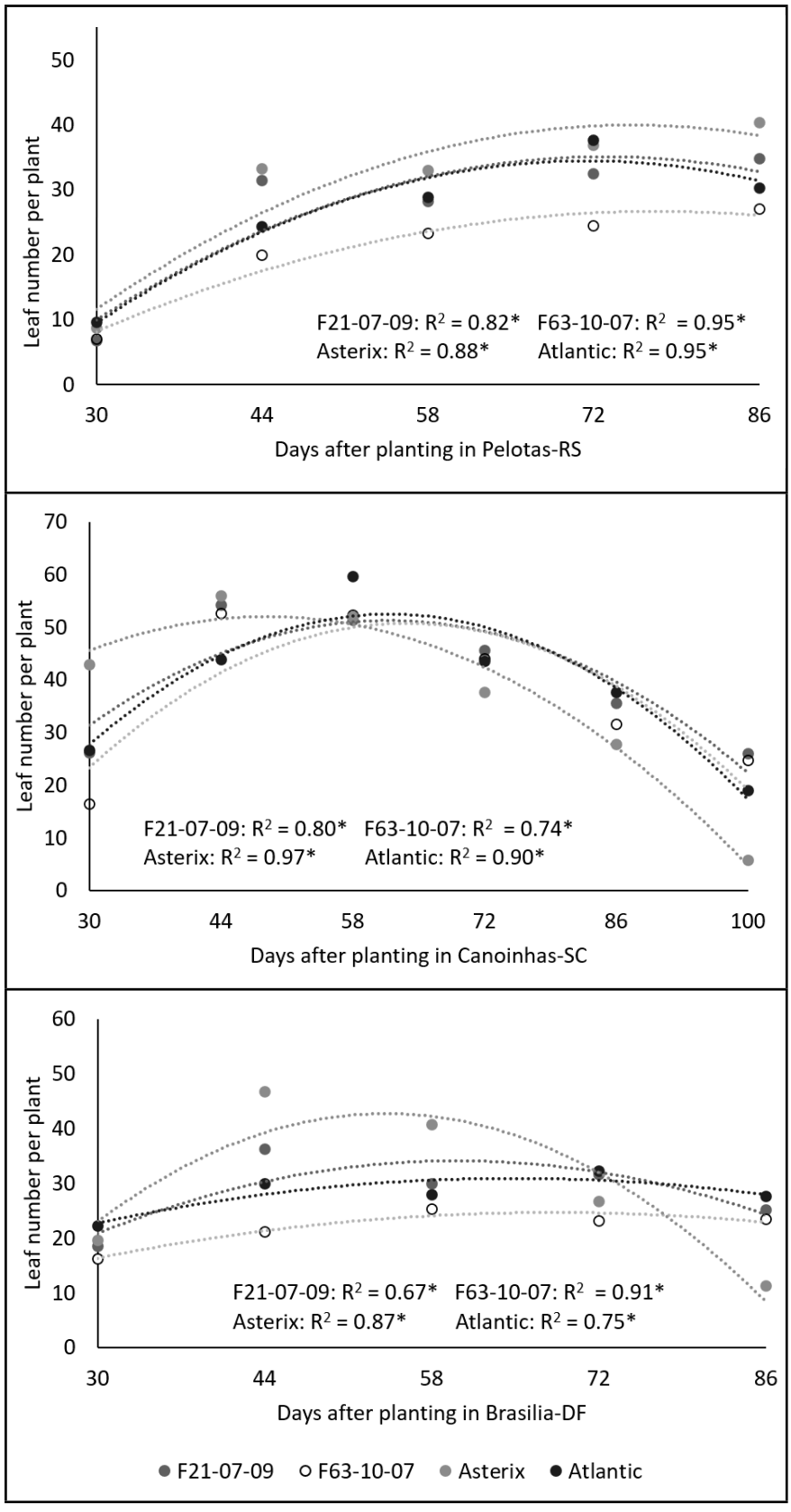

Figure 1. Progression functions of the leaf number per plant, of two potato clones and two cultivars in relation to days after planting in Pelotas-RS, Canoinhas-SC, and Brasília-DF, Brazil. R^2= coefficient of determination. *Significant at 5% by the F test. Pelotas-RS, Canoinhas-SC and Brasília-DF, Embrapa, 2021.

characteristic of presenting a large leaf number, but smaller leaves, therefore not corresponding to a higher leaf area index, in addition to being an early cultivar in Brazilian photoperiod conditions (Pereira *et al*., 2020) , which could explain this behavior.

Regarding the leaf mass per plant (Figure 2 and Box 1), while for Canoinhas and Pelotas, in spring cultivation in a subtropical region in southern Brazil, the clone F63-10-07 presented the highest values (222.96 to 377.60 g), followed by clone F21-07-09 (211.06 to 344.14 g) and lower values for the cultivars Atlantic (206 to 274.31 g) and mainly 'Asterix' (145.26 to 208.14g). In Brasília, in the Brazilian West Center, under winter cultivation in a tropical region, the opposite occurred, with superiority for the maximum point of accumulation of leaf mass for the cultivars Atlantic (280.48 g) and Asterix (231.70 g) and lower values for clones F63-10-07 (219.15 g) and F21-07-09 (202.16 g). However, towards the end of the cycle, in the last collection, while for Canoinhas and Pelotas the same trend remains, for Brasília there is a more pronounced decrease for 'Asterix' (74.74 g), maintaining superiority for 'Atlantic' (231.22 g) and intermediate values for clones F63-10-07 (136.16 g) and F21-07-09 (110.94 g). A similar situation of earlier decline for 'Asterix' was observed by Silva *et al*. (2022) in spring cultivation in southern Brazil and by Pereira *et al*. (2020) in winter conditions in a tropical region.

The leaf area index measures the relationship between the leaf area of plants and the area occupied by them in the field, and the higher it is, the greater photosynthetically active area would be if there is no shading (Santos *et al*., 2019). This estimate demonstrates that, in general, the values were higher in the two clones, mainly F63-10-07 (2.09 to 2.35), and lower in 'Asterix' (1.33 to 1.42) (Figure 3 and Box 1). The superiority of the clone F63-10-07, considering the average of the two locations, confirms that despite the smaller number of leaves, they are larger and, therefore, allow a greater area for interception of solar rays for

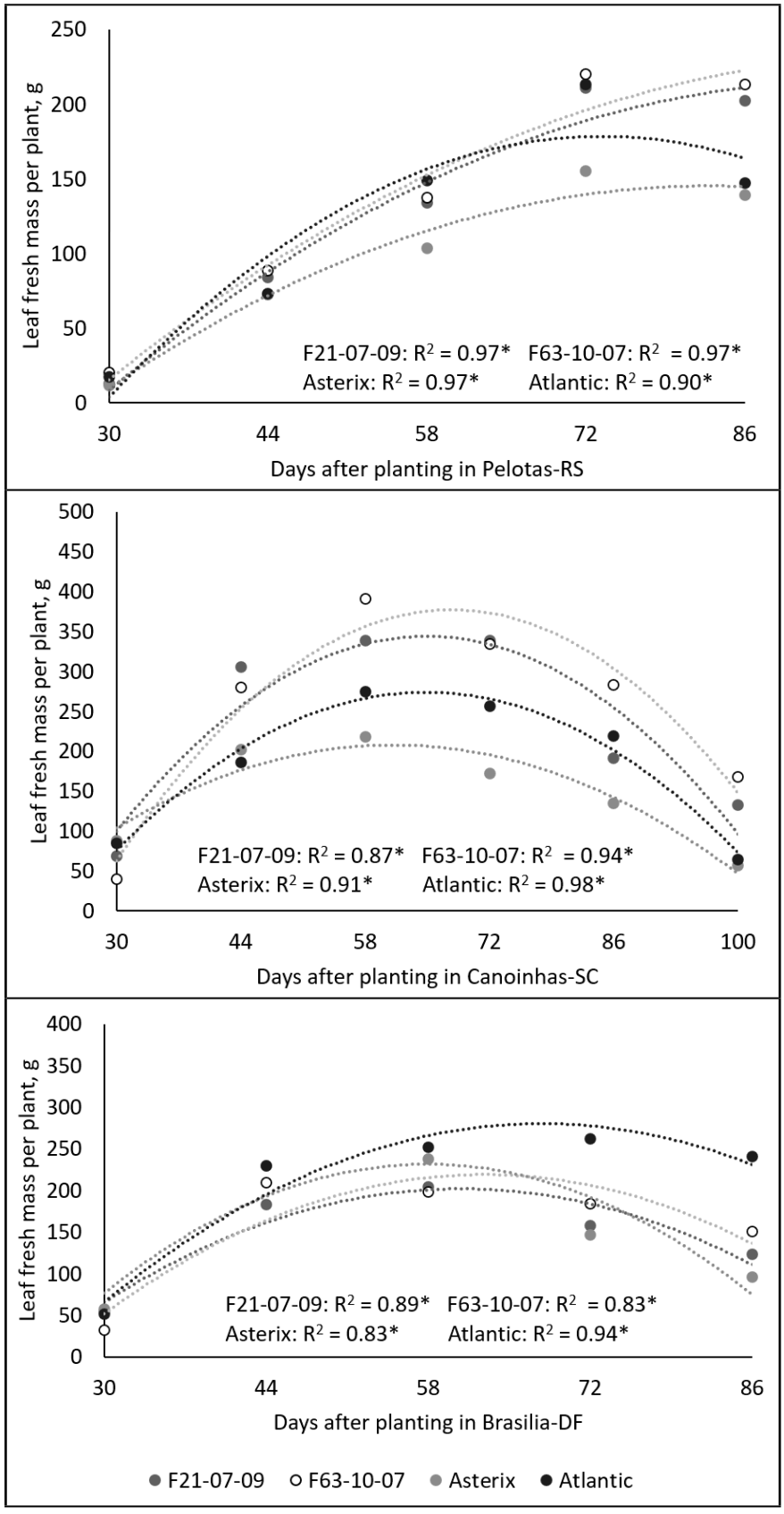

Figure 2. Progression functions of the leaf fresh mass (g/plant), of two potato clones and two cultivars in relation to days after planting in Pelotas-RS, Canoinhas-SC, and Brasília-DF, Brazil. R2= coefficient of determination. *Significant at 5% by the F test. Pelotas-RS, Canoinhas-SC and Brasília-DF, Embrapa, 2021.

Box 1. Functions of progression of leaf number per plant; leaf fresh mass per plant (g); leaf area index; stem number per plant; length of longest stem (cm); and tuber fresh mass (g/plant), of four potato genotypes evaluated in Pelotas-RS and Canoinhas-SC in the spring season, and in Brasília in the winter season, 2021. Pelotas-RS, Canoinhas-SC and Brasília-DF, Embrapa, 2021.

Genotype	Regression equation	Maximum point	Days
Leaf number per plant in Pelotas-RS			
F21-07-09	$y = -0.0136x^2 + 1.9854x - 37.333$	35.13	72.99
F63-10-07	$y = -0.0083x^2 + 1.2814x - 22.830$	26.62	77.19
Asterix	$y = -0.0139x^2 + 2.0879x - 38.554$	39.85	75.10
Atlantic	$y = -0.0146x^2 + 2.0814x - 39.838$	34.34	71.28
Leaf number per plant in Canoinhas-SC			
F21-07-09	$y = -0.0198x^2 + 2.4427x - 24.146$	51.19	61.68
F63-10-07	$y = -0.0241x^2 + 3.0727x - 47.167$	50.77	63.75
Asterix	$y = -0.0181x^2 + 1.7712x + 8.6776$	52.00	48.93
Atlantic	$y = -0.0243x^2 + 3.0094x - 40.715$	52.46	61.92
Leaf number per plant in Brasília-DF			
F21-07-09	$y = -0.0147x^2 + 1.7621x - 18.817$	33.99	59.93
F63-10-07	$y = -0.0057x^2 + 0.7786x - 1.8591$	24.73	68.30
Asterix	$y = -0.0339x^2 + 3.6679x - 56.543$	42.67	54.10
Atlantic	$y = -0.0068x^2 + 0.8769x + 2.5039$	30.77	64.48
Leaf fresh mass per plant in Pelotas-RS			
F21-07-09	$y = -0.0486x^2 + 9.2556x - 225.48$	211.06	86.00
F63-10-07	$y = -0.0425x^2 + 8.6344x - 205.27$	222.96	86.00
Asterix	$y = -0.0483x^2 + 8.012x - 187$	145.26	82.94
Atlantic	$y = -0.0929x^2 + 14x - 321.74$	206.00	75.35
Leaf fresh mass per plant in Canoinhas-SC			
F21-07-09	$y = -0.2009x^2 + 26.063x - 501.16$	344.14	64.86
F63-10-07	$y = -0.2208x^2 + 29.917x - 635.79$	377.60	67.75
Asterix	$y = -0.1072x^2 + 13.119x - 193.23$	208.14	61.19
Atlantic	$y = -0.1631x^2 + 21.161x - 412.06$	274.31	64.87
Leaf fresh mass per plant in Brasília-DF			
F21-07-09	$y = -0.1437x^2 + 17.475x - 329.11$	202.16	60.80
F63-10-07	$y = -0.1549x^2 + 19.472x - 392.79$	219.15	62.85
Asterix	$y = -0.1987x^2 + 23.008x - 434.34$	231.70	57.90
Atlantic	$y = -0.1495x^2 + 20.286x - 407.68$	280.48	67.85
Leaf area index in Pelotas-RS			
F21-07-09	$y = -0.0004x^2 + 0.0824x - 2.1624$	1.80	86.00
F63-10-07	$y = -0.0002x^2 + 0.057x - 1.3299$	2.09	86.00
Asterix	$y = -0.0005x^2 + 0.0791x - 1.7996$	1.33	79.10
Atlantic	$y = -0.00084x^2 + 0.1232x - 2.6143$	1.87	73.33
Leaf area index in Canoinhas-SC			
F21-07-09	$y = -0.0013x^2 + 0.1734x - 3.3313$	2.45	66.69
F63-10-07	$y = -0.0013x^2 + 0.179x - 3.8057$	2.35	68.85
Asterix	$y = -0.0008x^2 + 0.0953x - 1.4208$	1.42	59.56
Atlantic	$y = -0.0009x^2 + 0.1188x - 2.302$	1.62	66.00
Stem number per plant in Pelotas-RS			
F21-07-09	$y = -0.0024x^2 + 0.2837x - 3.3911$	4.99	59.10
F63-10-07	$y = 2.75$	2.75	44.00
Asterix	$y = 5,33$	5.33	44.00
Atlantic	$y = -0.0113x + 4.2893$	4.24	30.00

Genotype	Regression equation	Maximum point	Days
	Stem number per plant in Canoinhas-SC		
F21-07-09	$y = -0.0006x^2 + 0.0552x + 6.0028$	7.27	46.00
F63-10-07	$y = 5,92$	5.92	44.00
Asterix	$y = -0.0009x^2 + 0.0261x + 8.9549$	8.93	30.00
Atlantic	$y = -0.0017x^2 + 0.2083x - 0.4597$	5.92	61.26
	Stem number per plant in Brasília-DF		
F21-07-09	$y = -0.0004x^2 + 0.0571x + 3.2029$	5.24	71.38
F63-10-07	$y = 0.019x + 2.1413$	3.77	86.00
Asterix	$y = -0.0013x^2 + 0.1315x + 2.1015$	5.43	50.58
Atlantic	$y = -0.0006x^2 + 0.0773x + 0.7484$	3.24	64.42
	Length of the longest stem in Pelotas-RS		
F21-07-09	$y = -0.0111x^2 + 1.7325x - 33.505$	34.10	78.04
F63-10-07	$y = -0.0121x^2 + 1.8348x - 35.854$	33.70	75.82
Asterix	$y = -0.0116x^2 + 1.6517x - 29.69$	29.10	71.19
Atlantic	$y = -0.0159x^2 + 2.1546x - 39.96$	33.03	67.75
	Length of the longest stem in Canoinhas-SC		
F21-07-09	$y = -0.028x^2 + 4.2237x - 69.345$	89.94	75.42
F63-10-07	$y = -0.0208x^2 + 3.527x - 59.447$	90.07	84.78
Asterix	$y = -0.0233x^2 + 3.3989x - 46.586$	77.37	72.94
Atlantic	$y = -0.0182x^2 + 2.73x - 27.216$	75.16	75.00
	Length of the longest stem in Brasília-DF		
F21-07-09	$y = -0.0287x^2 + 3.6415x - 59.553$	55.96	63.44
F63-10-07	$y = -0.0275x^2 + 3.4518x - 56.821$	51.50	62.76
Asterix	$y = -0.0282x^2 + 3.6538x - 55.829$	62.52	67.78
Atlantic	$y = -0.0267x^2 + 3.4999x - 49.822$	64.87	65.54
	Tuber fresh mass in Pelotas-RS		
F21-07-09	$y = 10.056x - 377.81$	627.79	86.00
F63-10-07	$y = 9.7857x - 360.74$	617.83	86.00
Asterix	$y = 7.369x - 266.07$	470.83	86.00
Atlantic	$y = -0.0112x^2 + 10.059x - 333.74$	448.50	86.00
	Tuber fresh mass in Canoinhas-SC		
F21-07-09	$y = 0.0455x^2 + 9.4536x - 355.94$	1044.42	100.00
F63-10-07	$y = 0.0666x^2 + 5.8712x - 274.08$	979.04	100.00
Asterix	$y = -0.0723x^2 + 19.782x - 559.06$	696.14	100.00
Atlantic	$y = -0.0885x^2 + 25.413x - 746.37$	909.93	100.00
	Tuber fresh mass in Brasília-DF		
F21-07-09	$y = -0.2537x^2 + 45.705x - 1180.5$	877.98	90.08
F63-10-07	$y = -0.0885x^2 + 23.401x - 631.19$	823.94	100.00
Asterix	$y = -0.2286x^2 + 43.195x - 1094.8$	945.67	94.48
Atlantic	$y = -0.1926x^2 + 40.242x - 1054.9$	1043.30	100.00

Maximum point = maximum point of the regression; Days= number of days to the maximum point of the regression

photosynthesis. The clone F21-07-09 also stood out in this regard, mainly in Canoinhas, with values ranging from 1.80 to 2.45. Costa *et al*. (2015) obtained an average leaf area of 3,572.43 cm^2/ plant for the cultivar Atlantic, which in the spacing of the present work would be equivalent to 1.36, with the maximum point of the regression curve at 73.5 days.

Characters related to the development of the aboveground plant part, their distributions on the plant and also the stem number can be used to define the spacing between plants (Pereira *et al*., 2020). The stem number per plant may vary depending on the genetic characteristics of cultivars, as well as the sprouting stage and the size of the potato seed. Larger, longer-sprouting potato seed tends to produce more stems per plant (Fantaw *et al*., 2019). In the present study, the size of the potato seed and the storage time in a cold room to overcome dormancy were standardized, therefore the variation that occurred was due to genetic factors. According to Fernandes *et al*. (2010), the distribution of leaves over a greater number of stems can be an advantage, as it represents a reduction in self-shading. Therefore, there is no requirement regarding this characteristic, as variables such as the size of the seed and the time spent in a cold chamber to overcome dormancy or the planting density can be managed to obtain the number of stems per plant or by area, but for this it is important to characterize the genotypes.

'Asterix' had the highest stem number in all locations (5.33, 8.93, and 5.43, for Pelotas, Canoinhas and Brasília, respectively), followed by clone F21-07-09 (4.99, 7.27, and 5.24, respectively), while F63-10-07 (2.75, 5.92, and 3.77, respectively) and 'Atlantic' (4.24, 5.92 and 3.24, respectively) had fewer stem number (Figure 4 and Box 1). This behavior can be explained by the fact that genotypes with higher tuber dry matter content or specific gravity, as is the case of these last two genotypes, normally present longer dormancy and as a consequence tend to form fewer stems per plant (Mustefa *et al*., 2017). Pereira *et al*.

Table 1. Simple correlations between the morpho-agronomic characters in four potato genotypes in Pelotas-RS on the lower diagonal, and Canoinhas-SC on the upper diagonal, in the 2021 spring season. Pelotas-RS and Canoinhas-SC, Embrapa, 2021.

	TFM	LN	LFM	SN	LLS	LAI
TFM		0.57*	0.36*	-0.29	0.39*	0.37*
LN	0.37*		0.72*	0.62*	0.21	0.72*
LFM	0.85*	0.70*		0.27	0.62*	0.98*
SN	-0.07	0.48*	0.05		-0.07	0.34*
LLS	0.69*	0.74*	0.91*	0.04		0.63*
LAI	0.83*	0.71*	0.98*	0.07	0.90*	

TFM= tuber fresh mass (g/plant), LN= leaf number (number/plant), LFM= leaf fresh mass (g/plant), SN= stem number (number/plant), LLS= length of the longest stem (cm), and LAI= leaf area index. *Significant at 5% by t-test.

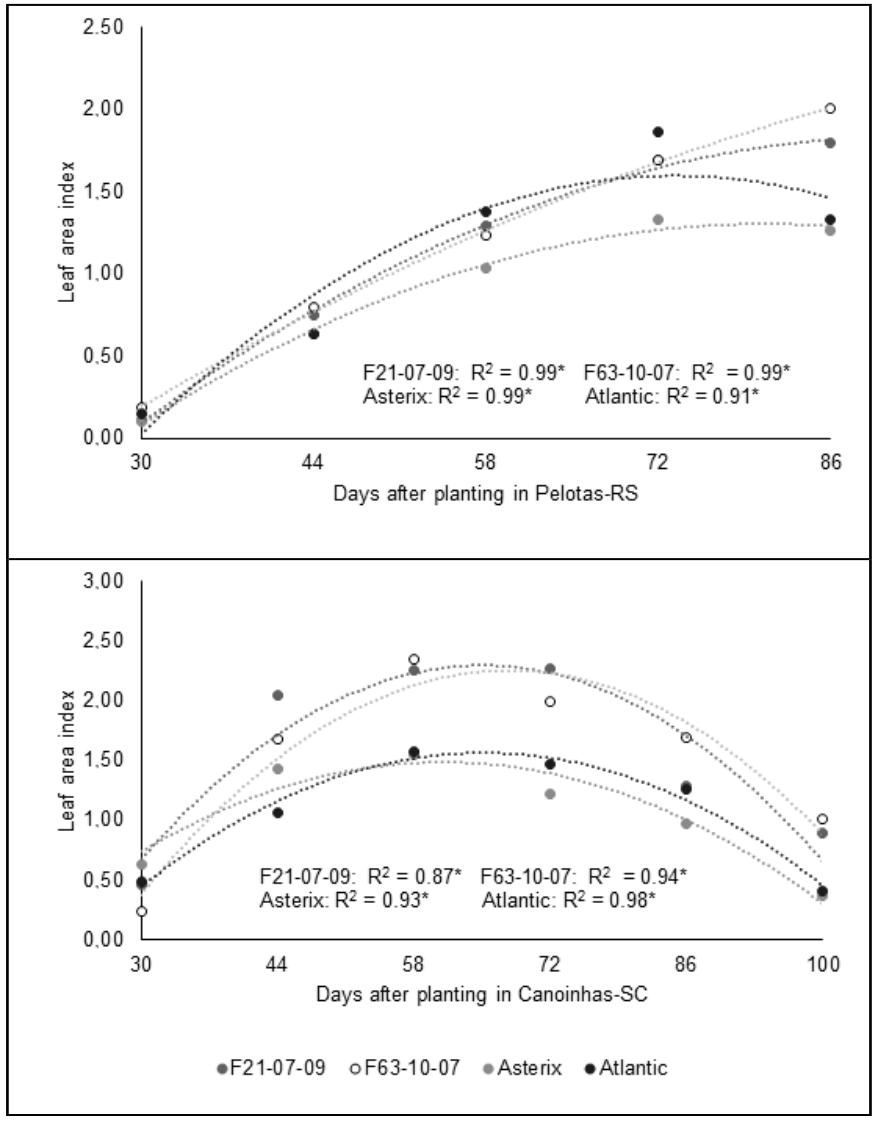

Figure 3. Progression functions of the leaf area index of two potato clones and two cultivars in relation to days after planting in Pelotas-RS and Canoinhas-SC, Brazil. R2= coefficient of determination. *Significant at 5% by the F test. Pelotas-RS and Canoinhas-SC, Embrapa, 2021.

(2020) also found a higher stem number for Asterix (6.00) and Agata (5.33), and lower for BRS F183 Potira (3.00) and BRSIPR Bel (3.17), with the last two having a higher tuber dry matter content.

The length of the longest stem is related to plant height, and longer stems tend to provide better distribution of leaves on the plant (Fernandes *et al*., 2010). There was great variation in the response of genotypes in different environments (Figure 5 and Box 1). In Pelotas, the length of the longest stem, which refers to the plant height or plant vigor, was generally shorter than in other locations. It was shorter for 'Asterix' (29.1 cm) and similar for the other genotypes, varying from 33.03 to 34.1 cm. In Canoinhas, the plants grew more, especially the clones F63-10-07 (90.07 cm) and F21-07-09 (89.94 cm), which were about 15 cm larger than the standard cultivars Asterix (77.37 cm) and Atlantic (75.16 cm). In Brasília, in general, the plants had intermediate growth height, with superiority for the cultivars Atlantic (64.87 cm) and Asterix (62.52 cm), and around 10 cm lower for the clones F21-07-09 (55.96 cm) and F63-10-07 (51.50 cm). Silva *et al*. (2018), in a subtropical ecosystem, obtained a value of 52.81 cm for 'Asterix', while Pereira *et al*. (2020), in a tropical ecosystem, found a value of 56.12 cm.

The total tuber mass produced by plants in Pelotas was higher for clones F21-07-09 (627.79 g) and F63-10-07 (617.83 g), and approximately 150 g lower for the cultivars Asterix (470.83 g) and Atlantic (448.50 g) (Figure 6 and Box 1). In Canoinhas, the highest tuber yield was obtained by the clone F21-07-09 (1,044.42 g), intermediate for F63-10-07 (979.04 g) and 'Atlantic' (909.93 g), and lower for 'Asterix' (696.14 g). In Brasília, the cultivars Atlantic (1,043.30 g) and Asterix (945.67 g) were superior to clones F21-07-09 (877.98 g) and F63-10-07 (823.94 g). Therefore, they show a tendency towards superiority in the total tuber mass for the genotypes and locations where there was also superiority for measures related to the aboveground part of the plants, mainly the mass of leaves per plant, indicating

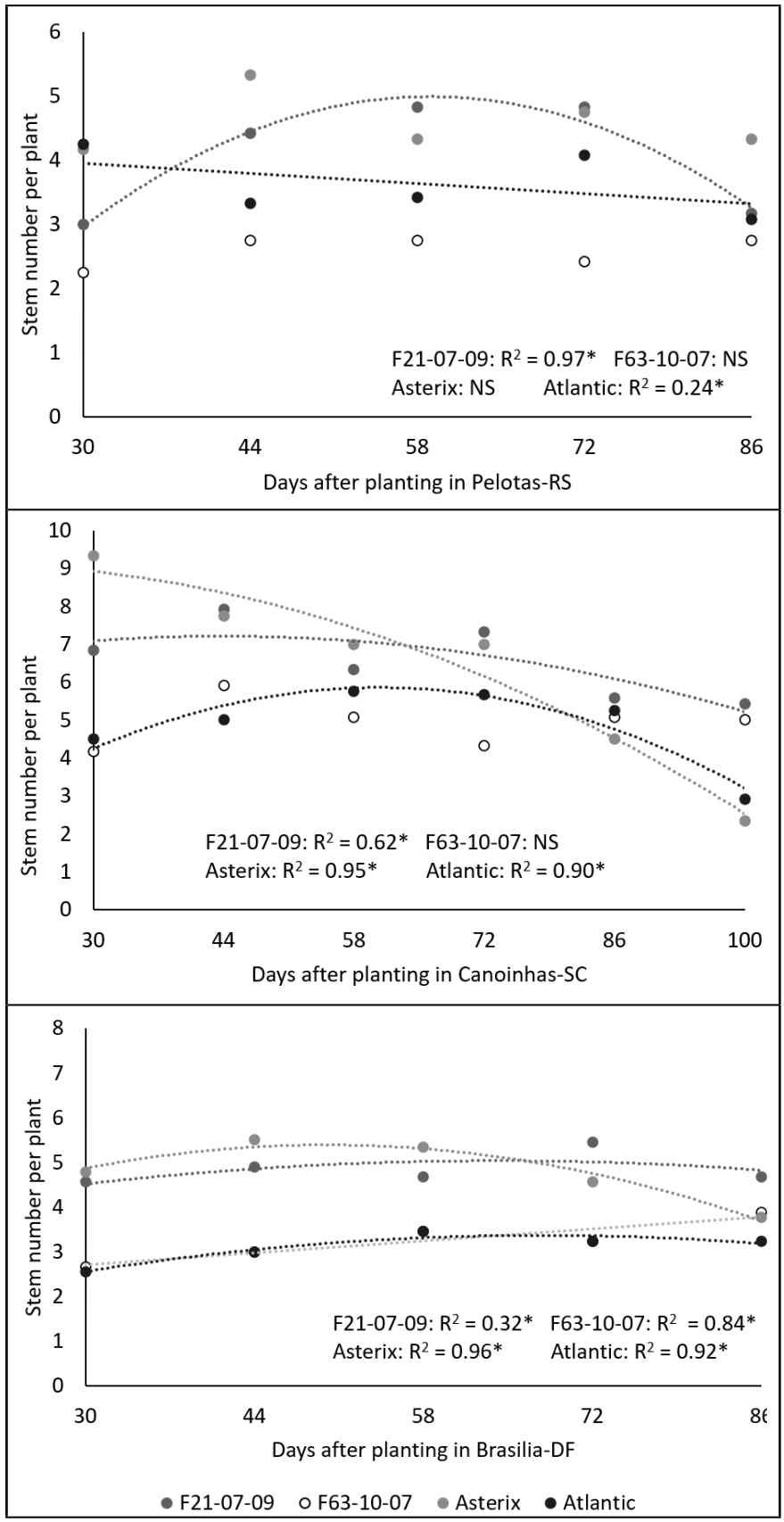

Figure 4. Progression functions of the stem number per plant (plant^{-1}), of two potato clones and two cultivars in relation to days after planting in Pelotas-RS, Canoinhas-SC, and Brasília-DF, Brazil. R2= coefficient of determination. *Significant at 5% by the F test. NS= not significant at 5% by the F test. Pelotas-RS, Canoinhas-SC and Brasília-DF, Embrapa, 2021.

a possible relationship between these characteristics.

To better understand the relationship between the measured characters in successive harvest periods, a simple correlation analysis was performed between the characters (Table 1). Significant correlations were observed between the characters that measure the aboveground plant parts, that is, leaf number, leaf fresh mass, stem fresh mass, length of the longest stem, and leaf area index. According to Silva *et al*. (2018), the characters that compose the vegetative plant aspect, such as stem number and size, and plant vigor, are related to the index of vegetative area available for photosynthesis.

The tuber fresh mass was correlated with aboveground characters, mainly with the leaf fresh mass (r= 0.36 to r= 0.85), the leaf area index (r= 0.37 to r= 0.83), the length of the longest stem (r= 0.39 to r= 0.69), and leaf number (r=0.37 to r=0.57).

Some studies have reported a direct relationship between these characters and tuber yield, such as plant height with tuber yield (Khayatnezhad *et al*., 2011; Fekadu *et al*., 2013), and plant vigor with tuber yield (Pereira *et al*., 2017).

Silva *et al*. (2020) also found a correlation between stem length and tuber mass (r= 0.64 to r= 0.76), as well as high values for the leaf area index and leaf mass (r= 0.97 to r= 0.98). Correlations between stem length and tuber mass were also reported by Khayatnezhad *et al*. (2011) (r= 0.84), Fantaw *et al*. (2019) (r= 0.42), Pereira *et al*. (2020) (r= 0.61) and Hunde *et al*. (2022) (r= 0.61 to r= 0.73), confirming that plants with greater aboveground part development tend to have a higher tuber yield.

Regarding tuber yield and frying quality evaluated at the end of the cycle (Table 2), an interaction between genotype and local was verified for most of the evaluated characters, except for the average tuber mass and specific gravity, therefore for these two characters data were presented for each genotype as an average across sites. The clone F21-07-09 was superior in relation to the marketable tuber number and, together

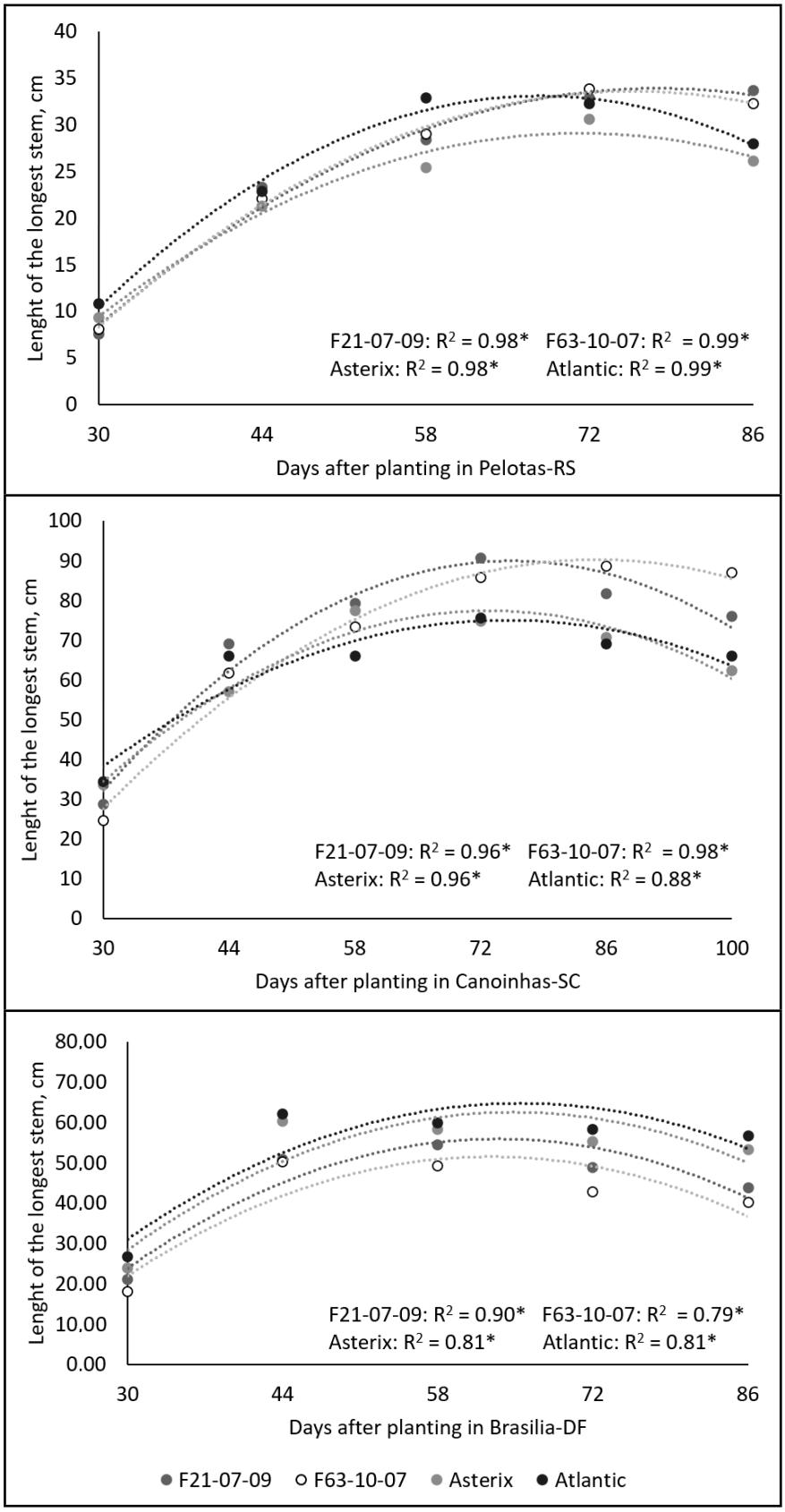

Figure 5. Progression functions of the length of longest stem (cm), of two potato clones and two cultivars in relation to days after planting in Pelotas-RS, Canoinhas-SC, and Brasília-DF, Brazil. R2= coefficient of determination. *Significant at 5% by the F test. Pelotas-RS, Canoinhas-SC and Brasília-DF, Embrapa, 2021.

with the clone F63-10-07, also superior values for the total tuber mass in Pelotas. The clones F21-07-09 and F63-10-07 were superior to the standard cultivars for marketable tuber mass in Pelotas, and together with the cultivar Atlantic they were also superior in Canoinhas. In Brasília, no significant differences were observed for the characters that measure tuber yield. On average, the tubers of the clone F63-10-07 and the cultivar Atlantic were heavier or larger than the other genotypes, which may be related to the lower stem number, since genotypes with a lower stem number in general tend to produce fewer, but larger tubers (Silva *et al*., 2020).

Regarding frying quality, 'Atlantic' (1.097) and F63-10-07 (1.098) presented the highest tuber specific gravity, and F21-07-09 was higher (1.090) than 'Asterix' (1.082). 'Atlantic' showed a lighter frying color in Pelotas, while in Canoinhas the frying quality of the clones and cultivars was equivalent according to the mean group analysis.

Therefore, we found in this study that there is a tendency towards greater tuber yield for genotypes with greater aboveground plant part development, reinforcing the importance of evaluating these characters. In general, there was greater development of the aboveground part and also a higher tuber yield for clones F21-07-09 and F63-10-07 in Pelotas, of these same clones in addition to the cultivar Atlantic in Canoinhas. This indicates good adaptation of these clones and potential to become new cultivars adapted for environments in southern Brazil.

In Brasília, the cultivars Asterix and Atlantic showed greater development of the aboveground plant part and higher tuber mass throughout the plants' vegetative cycle, although the differences in final marketable yield were not statistically significant. Regarding frying quality, the clone F63-10-07 and the cultivar Atlantic have the highest specific tuber gravity and the clone F21-07-09 is superior to the cultivar Asterix. Although 'Atlantic' was superior in relation to frying color in Pelotas, all genotypes performed equivalently in Canoinhas.

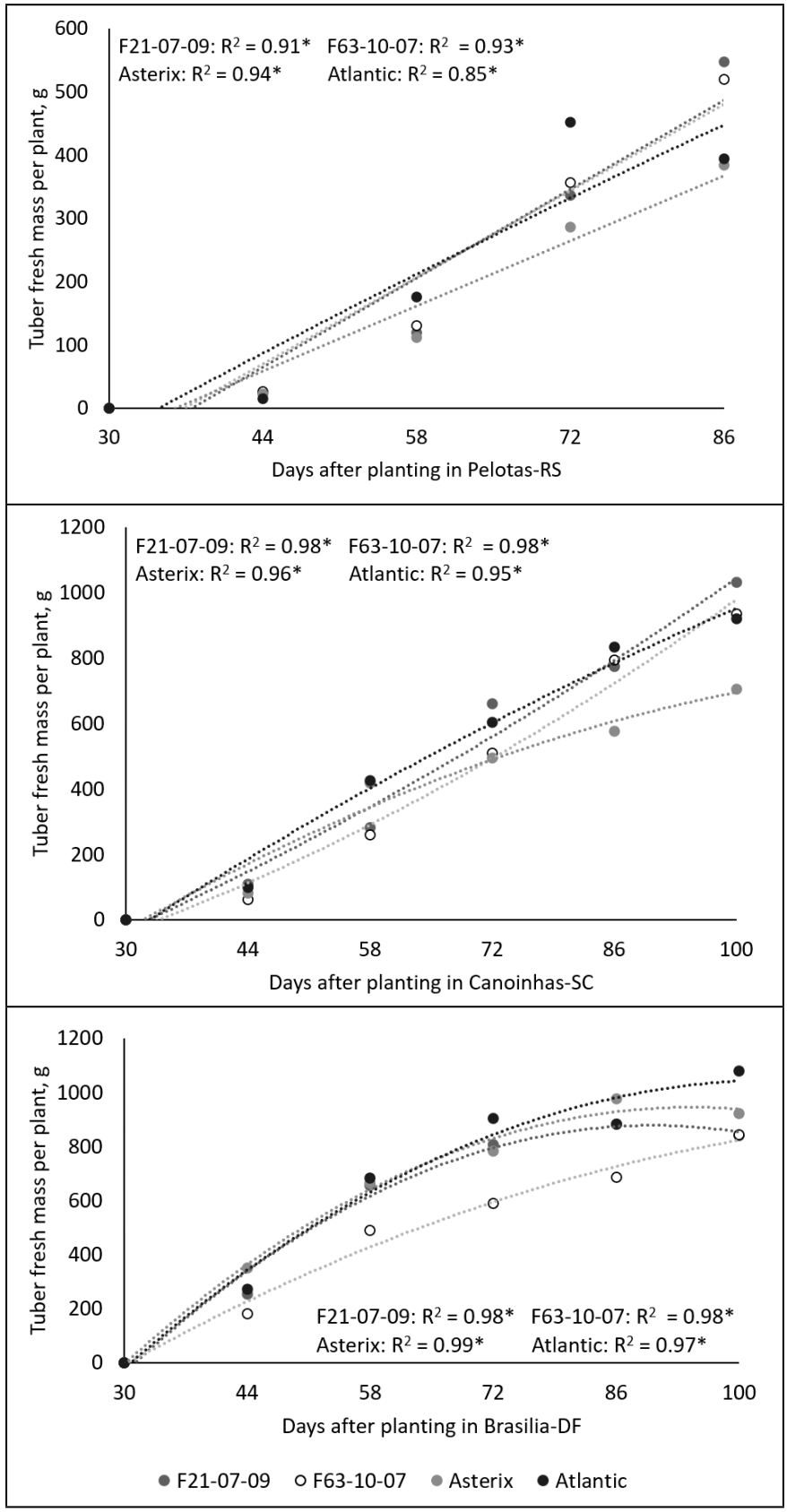

Figure 6. Progression functions of tuber fresh mass (g/plant), of two potato clones and two cultivars in relation to days after planting in Pelotas-RS, Canoinhas-SC, and Brasília-DF, Brazil. R2= coefficient of determination. *Significant at 5% by the F test. Pelotas-RS, Canoinhas-SC and Brasília-DF, Embrapa, 2021.

Table 2. Grouping of means for the characters that showed genotype x location interaction: number and mass of marketable tubers, total tuber mass, and frying color; and for each genotype in the average of the locations for the characters that did not show interaction between the factors: average tuber mass and specific gravity of tubers, evaluated in four potato genotypes in Pelotas-RS and Canoinhas-SC in the spring season and Brasília in the winter season, 2021. Pelotas-RS, Canoinhas-SC and Brasília-DF, Embrapa, 2021.

Genotype	Marketable tuber number (ha/1000)			Marketable tuber mass (t/ha)		
	Pelotas	Canoinhas	Brasília	Pelotas	Canoinhas	Brasília
F21-07-09	285.47 aA	165.71 aB	152.38 aB	28.95 aA	26.35 aA	27.99 aA
F63-10-07	190.16 bA	153.65 aA	191.67 aA	26.30 aA	29.20 aA	25.66 aA
Asterix	105.30 bB	108.57 aB	190.47 aA	12.45 bB	18.73 bB	29.15 aA
Atlantic	133.81 bA	132.06 aA	202.38 aA	14.48 bB	23.94 aA	32.31 aA
Mean	178.69	140.00	184.22	20.54	24.55	28.78
CV (%)	27.92	20.35	23.19	25.79	18.07	27.19
	Total tuber mass (t/ha)			Average tuber mass (g)		
	Pelotas	Canoinhas	Brasília	Pelotas and Canoinhas		
F21-07-09	33.97 aA	40.31 aA	34.77 aA	94.16 b		
F63-10-07	30.16 aA	40.95 aA	35.60 aA	115.01 a		
Asterix	18.18 bB	31.11 aA	36.27 aA	90.07 b		
Atlantic	16.13 bB	33.21 aA	36.52 aA	105.27 a		
Mean	24.61	36.40	35.79	101.13		
CV (%)	25.84	24.70	25.81	5.75		
	Specific gravity			Frying color		
	Pelotas and Canoinhas			Pelotas	Canoinhas	
F21-07-09	1.090 b			6.00 bB	8.67 aA	
F63-10-07	1.098 a			6.00 bB	8.67 aA	
Asterix	1.082 c			6.50 bA	7.66 aA	
Atlantic	1.097 a			8.00 aA	8.00 aA	
Mean	1.092			6.62	8.25	
CV (%)	0.05			14.93	6.06	

Means followed by different lowercase letters in the column and uppercase letters in the row differed significantly by Scott & Knott at $p<0.05$. CV (%)= coefficient of variation. Frying color notes from 1= dark to 9= light.

F63-10-07 and 'Atlantic', which have a higher tuber specific gravity, are characterized by also having a lower stem number per plant and, consequently, a high average tuber mass, indicating the need to manage seed sprouting and size, and planting spacing to adjust the crop stem density. The maximum point of development of the aboveground plant part of the clones, in general, occurs later compared to 'Asterix', with a vegetative cycle similar to the development of 'Atlantic'.

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