horticultura brasileira

Research

KAWAKAMI, J; ESCHEMBACK, V; MATOS, CK; MELO, PE. Morphological characters contributing to yield increase of potato cultivars in Brazil. *Horticultura Brasileira* v.41, 2023, elocation e274810. DOI: http://dx.doi.org/10.1590/s0102-0536-2023-e274810

Morphological characters contributing to yield increase of potato cultivars in Brazil

Jackson Kawakami [1]*; Vlandiney Eschemback [2]; Cinthia K de Matos [1]; Paulo Eduardo de Melo [3]

[1]Universidade Estadual do Centro Oeste (UNICENTRO), Guarapuava-PR, Brasil; jkawakami@unicentro.br (*author for correspondence); cinthiamatos82@gmail.com. [2]Hélix Seeds and Biotechnology Ltda., Londrina-PR, Brasil; vlandiney.eschemback@agroceres.com. [3] Secretaria de Inovação, Desenvolvimento Sustentável, Irrigação e Cooperativismo, Ministério da Agricultura e Pecuária, Brasilia-DF, Brasil; paulo.melo@embrapa.br

ABSTRACT

A previous study revealed that modern potato cultivars used in Brazil have higher commercial tuber yield than old cultivars. The objective of the present study was to clarify which morphological characters influence the yield gain of modern cultivars. Two field experiments were performed in Brazil: in Guarapuava-PR and Brasilia-DF. The treatments consisted of six cultivars, classified according to origin and year of release: Bintje (European, 1910), Baronesa (Brazilian, 1955), Monalisa (European, 1982), Agata (European, 1990), Catucha (Brazilian, 1995) and BRS Clara (Brazilian, 2010). These were the main cultivars used in southern Brazil in the last 65 years and represent 100 years of breeding. A randomized complete block design with six treatments and four replications was used. The following plant morphological characters were evaluated at four growth stages (the beginning of plant development, the beginning of tuberization, maximum shoot growth and tuber bulking stages): leaf area index, specific leaf area, number of main stems, initiated and bulked tubers. At 15 days after emergence, modern cultivars have higher leaf area index and bulked tubers compared to older cultivars. Also, a larger number of mainstems and smaller specific leaf area were observed in modern cultivars. A high leaf area index at the beginning of the growing development combined with a large number of bulked tubers contributed to the increase of the yield potential of modern cultivars.

Keywords: *Solanum tuberosum*, breeding, LAI, tuber, variety, yield potential.

RESUMO

Caracteres morfológicos que contribuem para o aumento da produtividade de cultivares de batata no Brasil

Um estudo anterior revelou que as cultivares modernas de batata, cultivadas no Brasil, têm maior produtividade comercial de tubérculos do que as cultivares antigas. O presente estudo teve como objetivo identificar quais caracteres morfológicos influenciam o ganho de produtividade das cultivares modernas. Dois experimentos de campo foram realizados no Brasil: em Guarapuava-PR e Brasília-DF. Os tratamentos consistiram de seis cultivares, classificadas de acordo com a origem e o ano de lançamento: Bintje (europeia, 1910), Baronesa (brasileira, 1955), Monalisa (europeia, 1982), Ágata (europeia, 1990), Catucha (brasileira, 1995) e BRS Clara (brasileira, 2010). Essas foram as principais cultivares utilizadas no sul do Brasil nos últimos 65 anos e representam 100 anos de melhoramento genético. Foi utilizado delineamento em blocos casualizados com seis tratamentos e quatro repetições. Foram avaliados os seguintes caracteres morfológicos das plantas em quatro estádios de crescimento (início do desenvolvimento vegetativo, início da tuberização, máximo crescimento vegetativo e enchimento de tubérculos): índice de área foliar, área foliar específica, número de hastes, tubérculos iniciados e formados. Aos 15 dias após a emergência, as cultivares modernas apresentaram maior índice de área foliar e tubérculos formados em comparação com as cultivares mais antigas. Além disso, maior número de hastes e menor área foliar específica foram observados nas cultivares modernas. Um índice de área foliar elevado no início do desenvolvimento vegetativo combinado com grande número de tubérculos formados contribuiu para o aumento do potencial de produtividade das cultivares modernas.

Palavras-chave: *Solanum tuberosum*, melhoramento, IAF, tubérculo, variedade, potencial de produtividade.

Received on May 27, 2023; accepted on July 19, 2023

Potato (*Solanum tuberosum*) is the fourth most important food crop in the world (FAOSTAT, 2023a). It is a vital crop as a food source because of the nutritional quality of its tubers, high efficiency in converting sunlight, water, carbon dioxide, and nutrients into high-quality food (Beals, 2019). Also, the consumption of this tuber is rising, especially in Africa and Asia where 70% increase in potato production from 1961 to 2013 was observed (Wijesinha-Bettoni & Mouillé, 2019). These continents are the places where both the population growth is higher and where the lack of food is more prominent than the world average (Masters *et al*., 2015).

In 1961 the world harvested 22 million ha, producing 270 million t with an average potato tuber yield of 12 t/ha (FAOSTAT, 2023b). After six decades, the harvested area decreased to 18 million ha, but the production increased to 376 million t, reaching an increase in tuber yield to 20.7 t/ha. Many factors lead to the increase in tuber yield, such as the use of high-quality seeds and early planting and consequent extending growth period were critical management at the beginning of the potato cultivation (Jansky & Spooner, 2018). Also, the development of modern chemical fertilizer, herbicides, insecticides and fungicides, mechanization, irrigation, and the reduction of post-harvest losses all contributed to the increase in yield (Bradshaw, 2009a). On the other hand, some authors stated that the development of modern potato cultivars had a small contribution for the yield increase (Bradshaw, 2009b; Simmonds, 1981), or even had no contribution at all (Douches *et al*., 1996; Love *et al*., 1998).

In Brazil, the harvested area of the potato crop was 191,255 ha in 1961 and decreased to 116,422 ha in 2021 (FAOSTAT, 2023b). The national potato production, however, increased from 1 million t in 1961 to 3.85 million t in 2021, reflecting the increase in tuber yield from 5.6 to 33.1 t/ha during this period (FAOSTAT, 2023b). The cause of this high increase in tuber yield in the country, however, is still not well studied. Improved crop management and new and more efficient agrochemicals would have contributed to this yield improvement. Also, the development of new potato genotypes would have contributed to the improvement of the national yield potential (Silva *et al*., 2012, 2014).

Our previous study comparing the most utilized potato cultivars in Brazil during the last hundred years (1910-2010) showed that the yield potential of modern potato cultivars was higher than of the old cultivars (Eschemback *et al*., 2017). However, this previous study did not identify which morphological plant characters contributed to the increase in the yield potential of modern cultivars. We believe that knowing this missing information could assist the national breeding programs to improve the development of new cultivars with high yield potential.

The objective of this study was to verify which morphological characters of the potato plants contributed to the increase in yield potential of the modern cultivars in Brazil.

MATERIAL AND METHODS

Two field experiments were carried out in Brazil in 2013. The first was conducted from January to April in Guarapuava-PR (25°23'37"S; 51°27'22"W). The climate in the region is Cfb: temperate, no dry season, warm summer, according to the Köppen classification (Beck *et al*., 2018). The soil is classified as Latossolo Bruno distrófico (Santos *et al*., 2018) or Typic Hapludox (Soil Survey Staff, 2014). The second was carried out from August to November, in Brasília-DF (15°46'48"S; 47°55'45"W). In this area, the soil is classified as Latossolo Vermelho distrófico típico (Santos *et al*., 2018) or Rhodic Hapludox (Soil Survey Staff, 2014). The local climate, according to the Köppen classification, is Aw: tropical savana, dry winter (Beck *et al*., 2018).

The experiments were planted during the growing seasons with appropriate climatic conditions for the crop in each region. In both areas, soil preparation began about one month before planting, with subsoiling and two harrowing. For planting, a light harrowing was performed with a subsequent furrowing of the area.

The treatments consisted of six cultivars classified by their origin and year of market release: Agata (European, 1990), Baronesa (Brazilian, 1955), Bintje (European, 1910), BRS Clara (Brazilian, 2010), Catucha (Brazilian, 1995) and Monalisa (European, 1982). Seed tubers of the same size (30-40 mm in diameter) received during July ~ September 2012 from importers (Bintje and Monalisa), research institutes (BRS Clara and Catucha) and seed growers (Agata and Baronesa) were used in Guarapuava's experiment. In Brasilia, we used tubers harvested in Guarapuava. The seed tubers were kept in a cold chamber at 4°C in the dark during about 4 months, and to standardize sprouting, the seed tubers were removed from the chamber about 15 days before planting. Planting was done manually, using row spacing of 0.80 m in both areas and 0.25 m between plants in Guarapuava and 0.30 m in Brasília, according to technical management carried out by producers for each region.

The foreign cultivars used were the main cultivated in South Brazil in the last 75 years and represent about 80% of what was planted by the producers during this period: cultivar Bintje from 1950, Monalisa, mainly in 1990, and cultivar Agata, from the beginning of the last decade to the present day. The Brazilian cultivars were selected with the same criterion of market relevance and commercial release date. Each experimental plot consisted of six rows with 18 plants each, arranged in randomized complete blocks with four replications in both experiments.

Fertilizer was supplied pre-planting, evenly distributed within the furrow in both experiments. Liming was not required in Guarapuava and fertilization consisted of 4 t/ha of the compound NPK (nitrogen, phosphorus and potassium) fertilizer 04-14-08, providing 160 kg/ha of N (urea), 560 kg/ha of P_2O_5 (single superphosphate) and 320 kg/ha of K_2O (potassium chloride). This amount of fertilization is a common practice performed by producers in this region and, as verified by Queiroz *et al*. (2013), the dose close to that appropriate for the culture in the region. In Brasília, according to soil analysis and estimating the yield of 30 t/ha, liming was performed with 2.5 t/ha of dolomitic limestone. Fertilization was performed to provide 40 kg/ha of N (urea), 600 kg/ha of P_2O_5 (triple superphosphate), 90 kg/ha of K_2O (potassium chloride), 2 kg/ha of B (borax) and 4 kg/ha of Zn (zinc sulfate). Cultural practices (weed, pest, and disease control) followed the standards adopted for each region (Pereira & Daniels, 2003). Late blight (*Phytophthora infestans*) control was sufficient to maintain green leaves to the end of samplings.

The experiment conducted in Brasília received irrigation according to the management traditionally used by Embrapa Vegetables to conduct experiments with the potato crop. The plants were hilled in both areas 15 days after emergence (DAE). In the evaluation of plant emergence, the number of plants per plot was quantified at intervals of 2 to 3 days until reaching 75% of emergence.

In the samples for growth analysis, four whole plants were collected from the useful area of each plot at four dates: 15, 30, 45 and 60 DAE, except for BRS Clara cultivar in Guarapuava, which was evaluated only at 15 DAE due to low plant emergence. These dates represent, respectively: the beginning of plant development, the beginning of tuberization, maximum shoot growth and tuber bulking stages. The variables evaluated were: leaf area index (LAI), specific leaf area, number of main stems (principal stem of each plant), number of nodes in the main stem, leaf dry weight (DW), bulked tuber DW (larger than 1 cm in its largest diameter), total DW (leaves + stems + tubers), number of tubers initiated (less than 1 cm in their smallest diameter), number of tubers bulked and average tuber fresh weight.

The samples were placed in a forced air circulation oven at 70°C until reaching constant weight for subsequent weighing to determine the DW. The LAI was estimated by quantifying a leaf area sample of about 2,000 cm^2 of each plot (four plants), with a leaf area integrating apparatus (Licor, model LI 3100, USA). The DW of these leave samples was quantified by estimating the specific leaf area (cm^2/g). Following the leaf DW of the plot, the planting density, and unit adjustments, we estimated the LAI of each plot.

Statistical analysis was performed by analyzing the average data obtained in the Guarapuava and Brasília experiments. Data were subjected to analysis of variance ($p<0.05$), and linear and quadratic regression, based on the years of the release of each cultivar as an independent variable. We chosed the regression model with the highest coefficient of determination (R^2).

RESULTS AND DISCUSSION

Our previous study showed that modern potato cultivars used in Brazil have higher tuber yield than old cultivars and this increase of yield potential was observed in cultivars released until 1980 (Eschemback *et al*., 2017). The present study explains which morphological characters contributed to the increase in the yield potential of cultivars launched until 1980.

No difference was observed in the period from planting to plant emergence between modern and old potato cultivars. On average, plants emerged 21 days after planting at both sites. Also, no significant difference was found for the number of nodes in the main stem among the cultivars studied, which showed an average of 8, 10, 13 and 15 nodes at 15, 30, 45 and 60 DAE, respectively. Modern cultivars produced larger LAI at 15 DAE than old cultivars, especially those cultivars released after 1980 (after cv. Monalisa) (Figure 1a). At 30, 45 and 60 DAE, there was no relationship between LAI and year of release of the studied cultivars (Figures

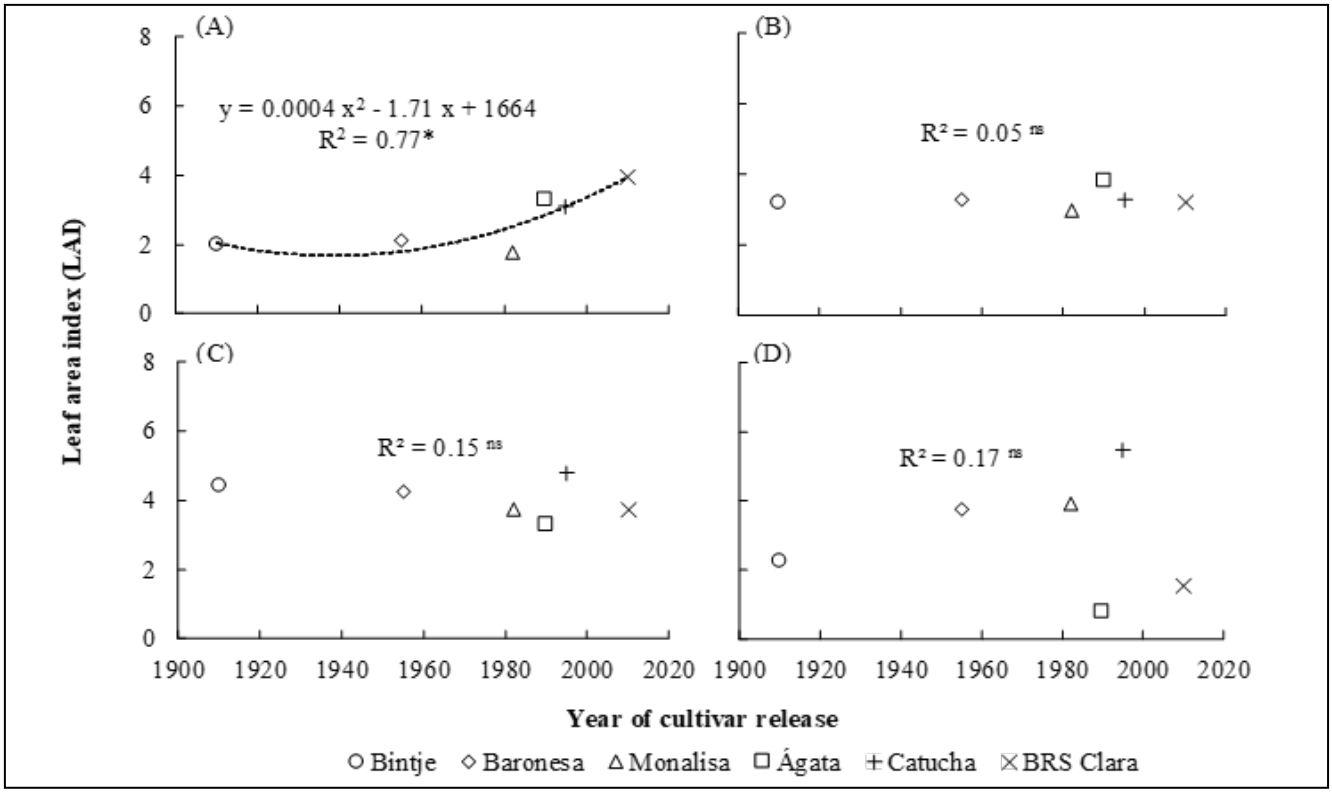

Figure 1. Relationship between leaf area index and year of potato cultivar release at 15 (A), 30 (B), 45 (C) and 60 (D) days after plant emergence. *significant at 5% error; ns= not significant. Guarapuava/Brasília, Unicentro/Embrapa Hortaliças, 2013.

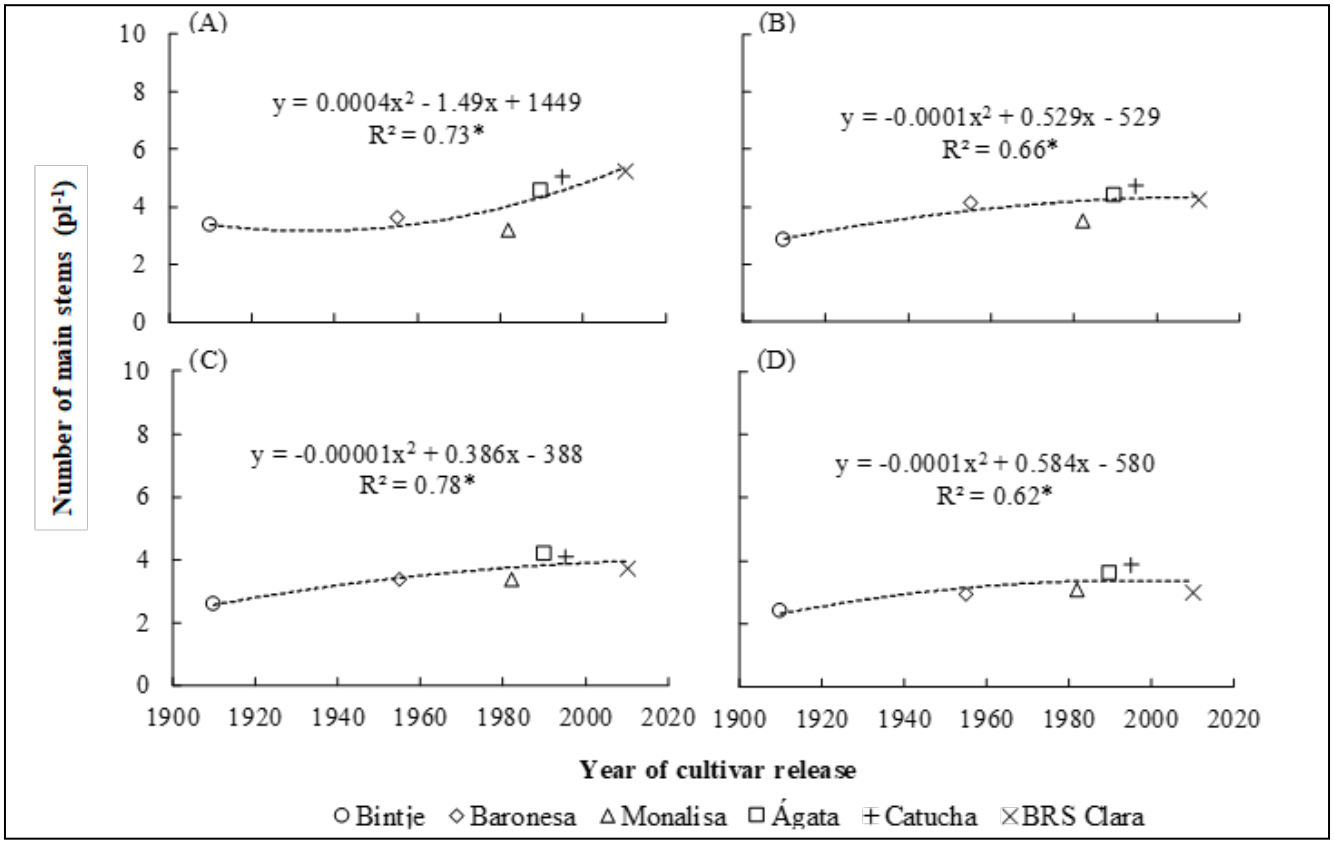

Figure 2. Relationship between the number of main stems/plant and year of potato cultivar release at 15 (A), 30 (B), 45 (C) and 60 (D) days after emergence (DAE). *significant at 5% error. Guarapuava/Brasília, Unicentro/Embrapa Hortaliças, 2013.

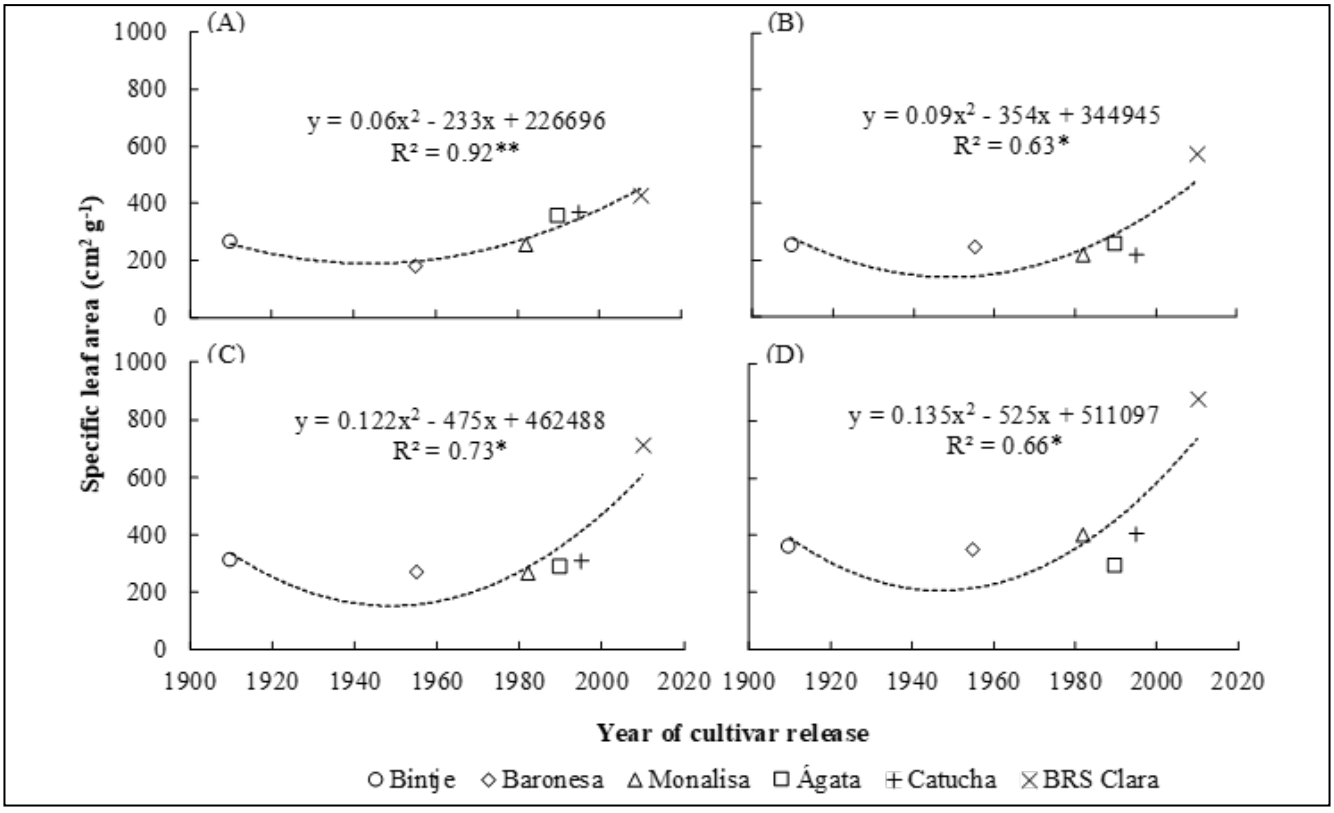

Figure 3. Relationship between specific leaf area ($cm^2\ g^{-1}$) and year of potato cultivar release at 15 (A), 30 (B), 45 (C) and 60 (D) days after plant emergence. **, *significant at 1% and 5% of error, respectively. Guarapuava/Brasília, Unicentro/Embrapa Hortaliças, 2013.

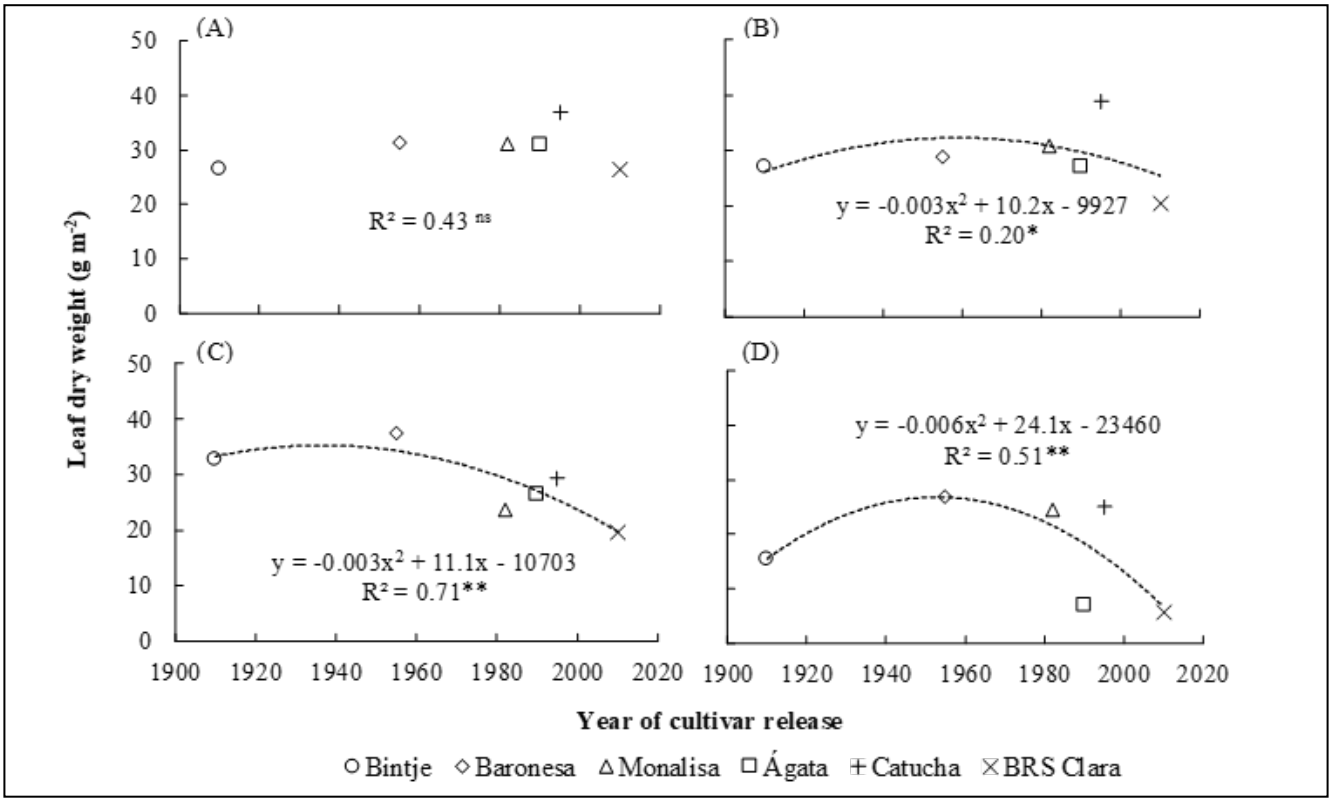

Figure 4. Relationship between leaf dry weight (g/m^2) and year of potato cultivars release at 15 (A), 30 (B), 45 (C) and 60 (D) days after plant emergence. **, *significant at 1% and 5% error, respectively; ns= not significant. Guarapuava/Brasília, Unicentro/Embrapa Hortaliças, 2013.

1b, 1c, and 1d).

The larger initial LAI in modern cultivars (Figure 1a) was due to higher plant growth of modern cultivars compared with old cultivars in the period between plant emergence and 15 DAE, since cultivars took a similar time to emerge. Seed tubers of different sizes may have different growth rates in the early plant development stage (Kawakami & Iwama, 2012). In this study we used seed tuber of the same size at planting. Therefore, differences in initial plant growth were not due to size of seed tubers used. Also, the larger initial LAI of modern cultivars compared with old cultivars was not due to the higher number of nodes in the main stem, as this variable may reflect the number of leaves per stem (Struik, 2007) and consequently the LAI. The higher number of main stems, along with the larger specific leaf area, resulted in higher initial LAI (i.e., 15 DAE) in modern cultivars compared with old cultivars. We speculate that modern cultivars have higher yield potential than old cultivars, in part, due to their ability to form higher LAI early in plant development. Studies revealed that the yield of the potato crop is directly related to how quickly plants reach maximum LAI, coupled with longevity and efficiency of photosynthetic activity of formed leaves (Boyd *et al*., 2002).

We observed a relationship between the number of main stems and year of cultivar release. Modern cultivars (Agata, Catucha and BRS Clara) produced the largest number of main stems since the beginning of plant development (Figure 2a). These cultivars maintained the largest number of stems throughout the growing development (Figure 2b, 2c, 2d). Quadratic regression was verified between specific leaf area and year of cultivar release. In general, modern cultivars, especially BRS Clara, produced leaves with larger specific leaf area than older ones (Figure 3a, 3b, 3c, 3d). A relationship was observed at 30, 45 and 60 DAE between leaf DW and year of cultivar release. In general, modern cultivars had lower leaf DW at 30, 45 and 60 DAE, especially Agata and BRS Clara, compared to older cultivars (Figure 4b, 4c, 4d). Although a higher number of main stems (Figure 2) and greater specific leaf area (Figure 3) in the modern cultivars than in old cultivars were observed at all sampling dates, there was no relationship between LAI and year of cultivars release at 30, 45 and 60 DAE (Figure 1).

Studies reported that potato plants receive low light incidence into the lower part of canopy; this is caused by shading of the upper leaves when reaching LAI around 3 (Camargo *et al*., 2016). In this work, shading suffered by leaves of lower canopy may have occurred in the modern cultivars that produced higher LAI at 15 DAE, a fact that may have led to senescence and loss of the lower leaves of these cultivars. Indeed, the lower leaf DW of modern cultivar compared with old cultivars, especially after 45 DAE, support this speculation. Also, despite the absence of any relationship between year of cultivar release and LAI from 30 DAE onward, it is evident that the leaf area produced by all cultivars was sufficient to intercept most of the incoming light.

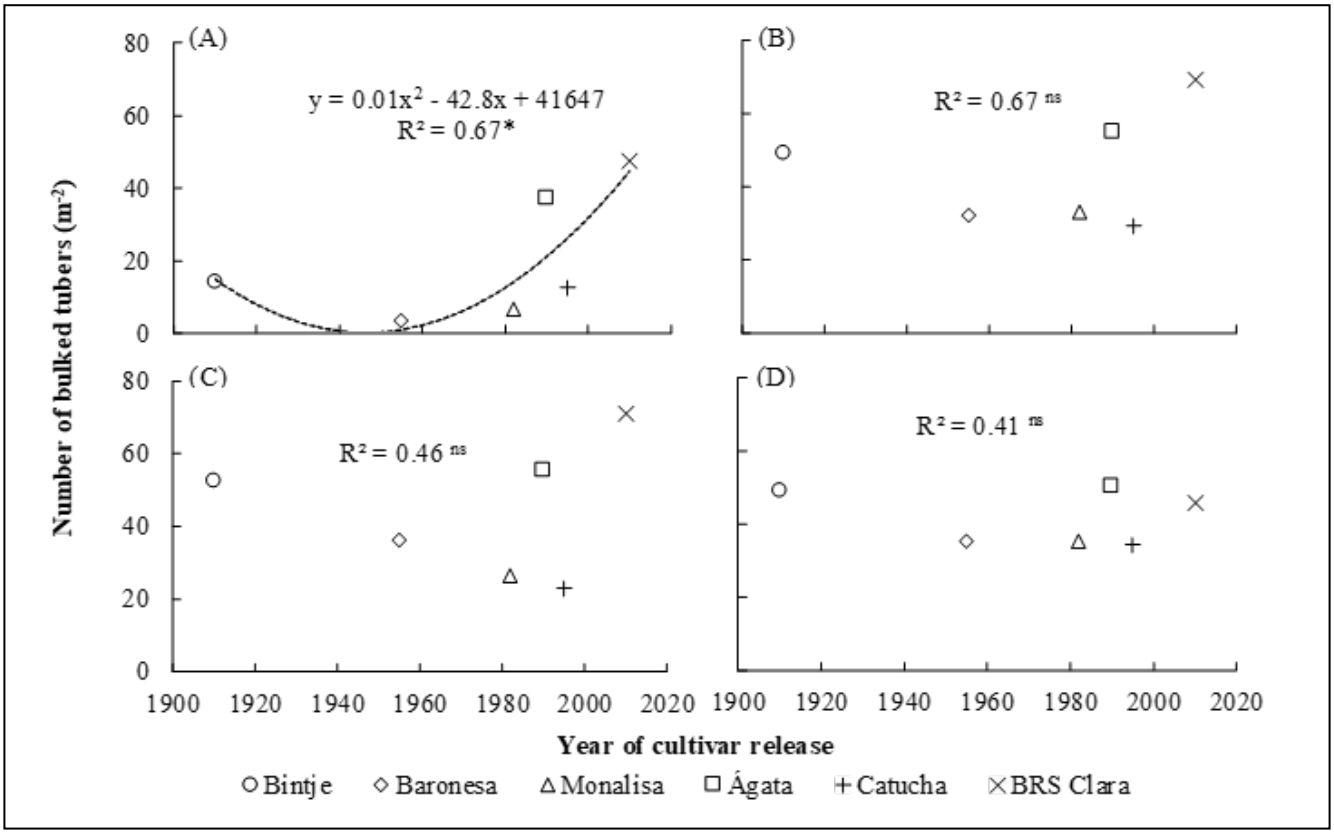

Figure 5. Relationship between the number/m² of bulked tubers (>1 cm) and year of potato cultivars release at 15 (A), 30 (B), 45 (C) and 60 (D) days after plant emergence. *significant at 5% error; ns= not significant. Guarapuava/Brasília, Unicentro/Embrapa Hortaliças, 2013.

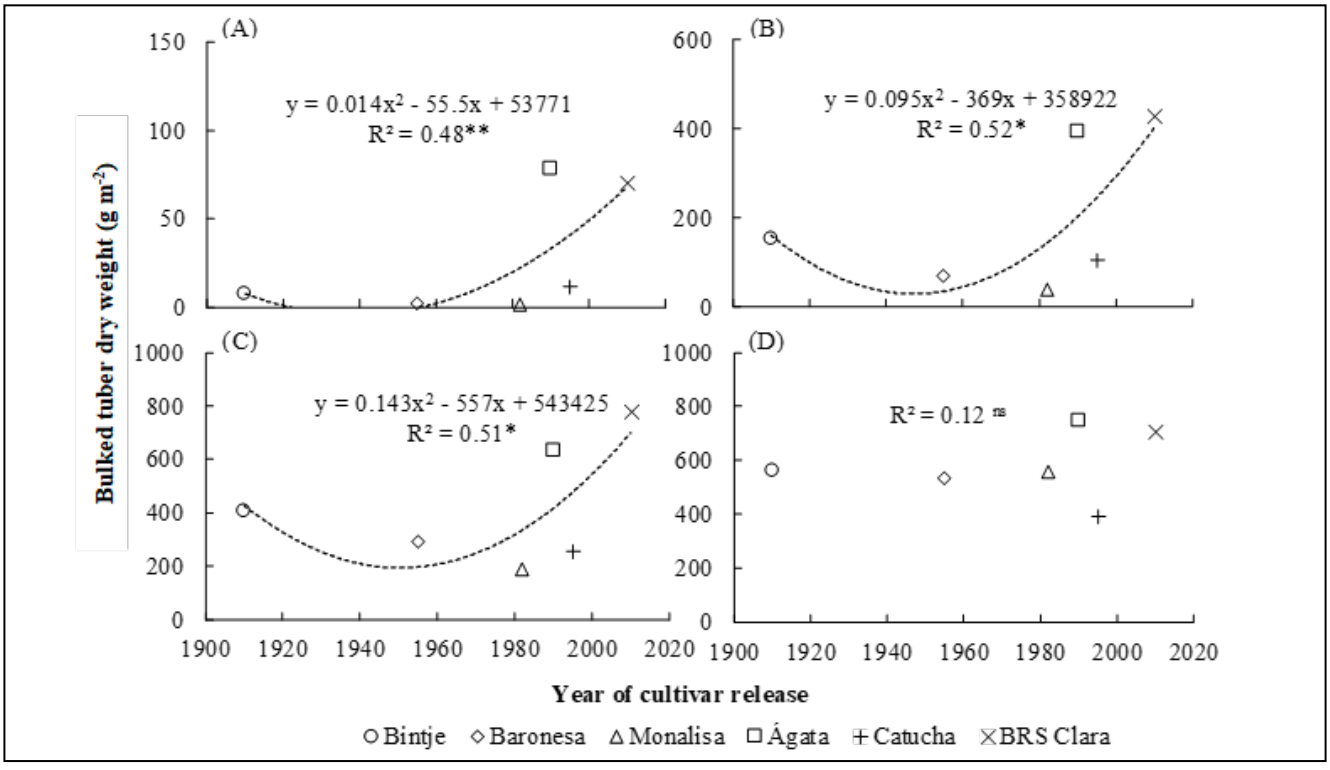

Figure 6. Relationship between bulked tuber dry weight (g/m²) and year of potato cultivar release at 15 (A), 30 (B), 45 (C) and 60 (D) days after plant emergence. **, *significant at 1% and 5% error, respectively; ns= not significant. Guarapuava/Brasília, Unicentro/Embrapa Hortaliças, 2013.

LAI around 3 was maintained by all cultivars during most of the growing development resulting in absorbance of almost all incoming light.

No relationship was observed between number of tubers initiated (<1 cm) and year of cultivar release, which initiated on average 19, 17, 15 and 7 tubers per plant at 15, 30, 45 and 60 DAE, respectively. However, a relationship was observed between the number of tubers bulked (>1 cm) and the year of cultivars release at 15 DAE (Figure 5a). Cultivars released from 1950 onwards produced a larger number of tubers than older cultivars, and the cultivar BRS Clara, the most modern one used in the study, produced the largest number of tubers: 47 tubers/m^2. At 30, 45 and 60 DAE, no significant relationship was observed between number of tubers bulked and year of cultivar release (Figure 5b, 5c, 5d).

There was no relationship between total DW of the plants and year of cultivar release, which showed an average of 192, 452, 709 and 765 g/m^2, at 15, 30, 45 and 60 DAE, respectively. However, a relationship was observed between tuber DW and year of cultivar release, at 15, 30 and 45 DAE, with higher tuber DW accumulation in modern cultivars (Agata and BRS Clara) compared to older cultivars (Figure 6a, 6b, 6c). At 60 DAE, there was no relationship between tuber DW and year of cultivar release (Figure 6d).

A relationship was observed between average tuber fresh weight and year of cultivar release in all evaluated dates. Modern cultivars produced higher average tuber fresh weight at 15 DAE, especially Agata and BRS Clara (Figure 7a). These cultivars remained to produce heavier tubers at 30, 45 and 60 DAE compared to older cultivars (Figure 7b, 7c, 7d).

It is supposed that the higher yield potential of modern cultivars (Eschemback *et al*., 2017) was not due to initiating tubers earlier than old cultivars. The higher yield potential in modern cultivars was due to a greater capacity to form bulky tubers (Figure 5), higher DW accumulation in these tubers (Figure 6) and higher tuber production with larger average fresh weight (Figure 7) early in plant development (i.e., 15 DAE). A study found that higher tuber DW accumulation was most benefited by the larger LAI and higher efficiency in the production and redistribution of photoassimilates (Silva *et al*., 2009). Studies found a positive correlation between tuber DW and LAI at the beginning of vegetative development and during the tuberization period (Tekalign & Hammes, 2005). Thus, the high LAI at 15 DAE supported the large number of bulky tubers produced by the plants of the modern cultivars observed in this study. Modern cultivars were benefited from the higher accumulation of tuber DW at the beginning of the growing development, as well as in the tuber bulking period.

Dry weight accumulation results from the photosynthetic activity and its distribution along different parts of the plant is a vital process in crop yield (Silva *et al*., 2009). About 90%

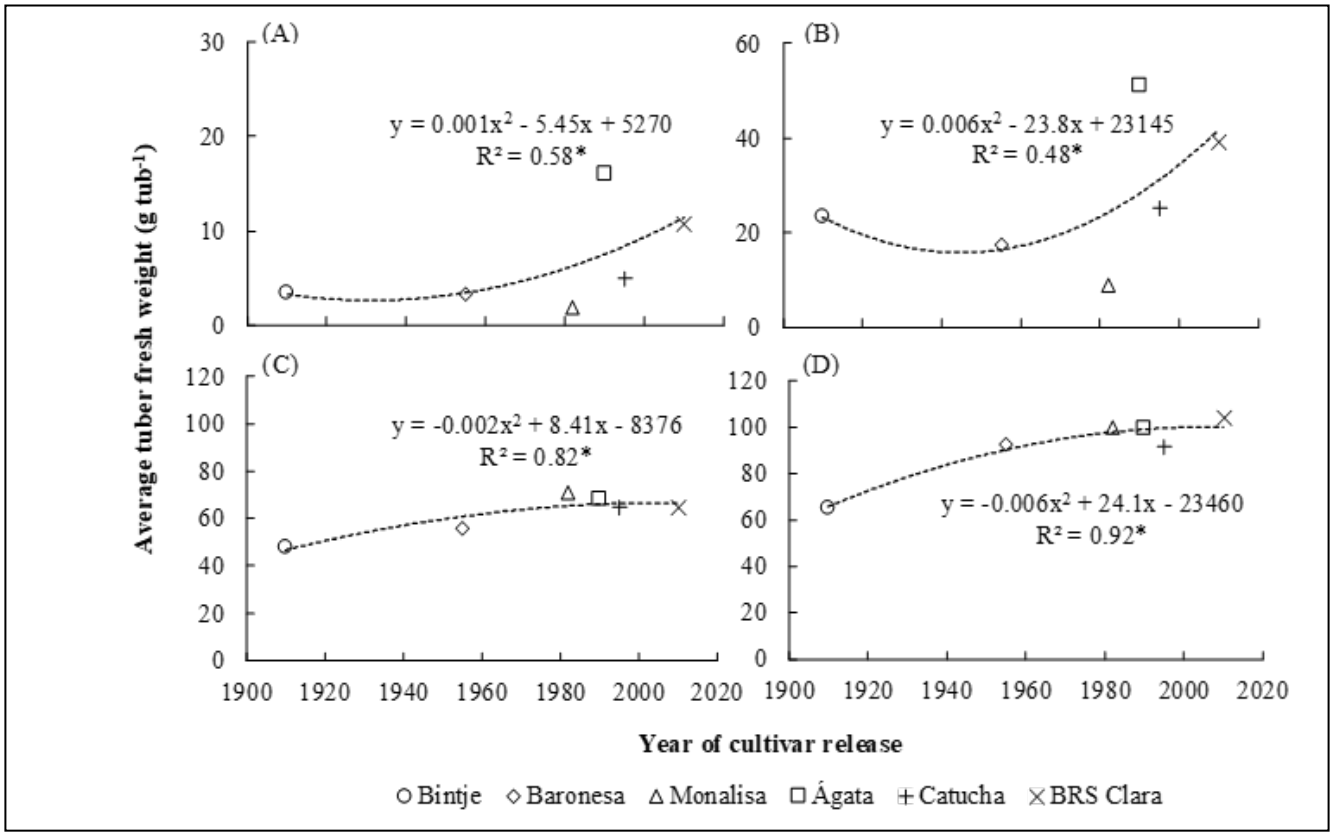

Figure 7. Relationship between average tuber fresh weight (g/tuber) and year of potato cultivar release at 15 (A), 30 (B), 45 (C) and 60 (D) days after plant emergence. *significant at 5% error. Guarapuava/Brasília, Unicentro/Embrapa Hortaliças, 2013.

of total DW accumulated over the growing period is from photosynthetic activity, and the other 10% is due to the absorption of mineral nutrients (Kolbe & Stephan-Beckmann, 1997). Thus, the increase in yield potential observed in modern cultivars, released on the market until 1980, was not due to the ability of these cultivars to perform more photosynthesis, since there was no difference in the accumulation of total DW in the studied cultivars (Figure 5). However, as modern cultivars accumulated higher DW in the tubers at the beginning of the development until 45 DAE (Figure 6a, 6b, 6c), we can conclude that these cultivars had a higher initial harvest index compared to the old cultivars.

In conclusion, a high LAI produced at the beginning of the plant development coupled with many bulky tubers contributed to the yield potential increase in modern cultivars.

REFERENCES

BEALS, KA. 2019. Potatoes, nutrition and health. *American Journal of Potato Research* 96: 102-110.

BECK, HE; ZIMMERMANN, NE; MCVICAR, TR; VERGOPOLAN, N; BERG, A; WOOD, EF. 2018. Present and future Köppen-Geiger climate classification maps at 1-km resolution. *Scientific Data* 5: 180214.

BOYD, NS; GORDON, R; MARTIN, RC. 2002. Relationship between leaf area index and ground cover in potato under different management conditions. *Potato Research* 45: 117-129.

BRADSHAW, JE. 2009a. Potato breeding at the Scottish plant breeding station and the Scottish crop research institute: 1920–2008. *Potato Research* 52: 141-172.

BRADSHAW, JE. 2009b. A genetic perspective on yield plateau in potato. *Potato Journal* 36: 79-94.

CAMARGO, DC; MONTOYA, F; MORENO, MA; ORTEGA, JF; CÓRCOLES, JI. 2016. Impact of water deficit on light interception, radiation use efficiency and leaf area index in a potato crop (*Solanum tuberosum* L.). *The Journal of Agricultural Science* 154: 662-673.

DOUCHES, DS; MAAS, D; JASTRZEBSKI, K; CHASE, RW. 1996. Assessment of potato breeding progress in the USA over the last century. *Crop Science* 36: 1544-1552.

ESCHEMBACK, V; KAWAKAMI, J; MELO, PE. 2017. Performance of modern and old, European and national potato cultivars in different environments. *Horticultura Brasileira* 35: 377-384.

FAOSTAT. 2023a. *Data - Food Balances*. Available at: https://www.fao.org/faostat/en/#data/FBS. Accessed on July 14, 2023.

FAOSTAT. 2023b. *Data - Crops and livestock products*. Available at: https://www.fao.org/faostat/en/#data/QCL. Accessed on April 19,l 2023.

JANSKY, SH; SPOONER, DM. 2018. The evolution of potato breeding. *Plant Breeding Reviews* 41: 169-214.

KAWAKAMI, J; IWAMA, K. 2012. Effect of potato microtuber size on the growth and yield performance of field grown plants. *Plant Production Science* 15: 144-148.

KOLBE, H; STEPHAN-BECKMANN, S. 1997. Development, growth and chemical composition of the potato crop (*Solanum tuberosum* L.). II. Tuber and whole plant. *Potato Research* 40: 135-153.

LOVE, SL; PAVEK, JJ; THOMPSON-JOHNS, A; BOHL, W. 1998. Breeding progress for potato chip quality in North American cultivars. *American Journal of Potato Research* 75: 27-36.

MASTERS, WA; COLAIEZZI, B; DENNISON, K; HILL, J; JORDAN-BELL, E; KABLAN, A; THURBER, M; WEATHERSPOON, LJ; OEHMKE, J. 2015. Agricultural policy for improved nutrition in Africa and Asia: Evidence to guide the US Government's investments in food security. *Food Security* 7: 747-750.

PEREIRA, AS; DANIELS, J. 2003. *O cultivo da batata na região sul do Brasil*. Brasília, BR: Embrapa. 567p.

QUEIRÓZ, LDM; KAWAKAMI, J; MULLER, M; OLIARI, I; UMBURANAS, R; ESCHEMBACK, V. 2013. Adubação NPK e tamanho da batata-semente no crescimento, produtividade e rentabilidade de plantas de batata. *Horticultura Brasileira* 31: 119-127.

SANTOS, HG; JACOMINE, PKT; ANJOS, LHC; OLIVEIRA, VA; LUMBRERAS, JF; COELHO, MR; ALMEIDA, JA; ARAUJO FILHO, JC; OLIVEIRA, JB; CUNHA, TJF. 2018. *Sistema Brasileiro de Classificação de Solos*. Brasília, BR: Embrapa. 356p.

SILVA, FL, PINTO, CABP; ALVES, JD; BENITES, FRG; ANDRADE, CM; RODRIGUES, GB; LEPRE, AL; BHERING, LL. 2009. Caracterização morfofisiológica de clones precoces e tardios de batata visando à adaptação a condições tropicais. *Bragantia* 68: 295-302.

SILVA, GO; BORTOLETTO, AC; PONIJALEKI, R; MOGOR, AF; PEREIRA, AS. 2014. Desempenho de cultivares nacionais de batata para produtividade de tubérculos. *Revista Ceres* 61: 752.

SILVA, GO; CASTRO, CM; TERRES, LR; ROHR, A; SUINAGA, FA; PEREIRA, AS. 2012. Desempenho agronômico de clones elite de batata. *Horticultura Brasileira* 30: 557-560.

SIMMONDS, NW. 1981. Genotype (G), Environment (E) and GE components of crop yields. *Experimental Agriculture* 17: 35-362.

SOIL SURVEY STAFF. 2014. *Keys to soil taxonomy*. USDA-Natural Resources Conservation Service.

STRUIK, PC. 2007. Above-ground and below-ground plant development. *Potato Biology and Biotechnology* 219-236.

TEKALIGN, T; HAMMES, PS. 2005. Growth and productivity of potato as influenced by cultivar and reproductive growth. II. Growth analysis, tuber yield and quality. *Scientia Horticulturae* 105: 29-44.

WIJESINHA-BETTONI, R; MOUILLÉ, B. 2019. The contribution of potatoes to global food security, nutrition and healthy diets. *American Journal of Potato Research* 96: 139-149.