Growth and dry matter partitioning of potato influenced by paclobutrazol applied to seed tuber

Crecimiento y partición de materia seca de papa influenciada por paclobutrazol aplicado al tubérculo-semilla

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Potato production field.
Photo: F.F. Araújo
ABSTRACT
Under cultivation conditions that favor the growth of plant shoot, the adoption of management practices that reduce the size of potato plants can be an alternative to increase the yield of tubers. The objective of this work was to evaluate the effect of paclobutrazol on vegetative growth and dry matter partitioning of the potato plant cv. Markies cultivated under summer conditions in the state of Minas Gerais. Treatments were 0.1, 1.0, 10 and 100 mg L\(^{-1}\) of paclobutrazol (PBZ) applied to the sprouted seeds before planting and control with water. PBZ was efficient in reducing plant height. PBZ treatments at doses 10 and 100 mg L\(^{-1}\) delayed the emergence of shoots and the beginning of plant tuberization. PBZ at 0.1 mg L\(^{-1}\) reduced the length of the stem by 18%, but did not differ from the control in relation to fresh and dry mass content, total production, specific gravity and starch content of tubers. Treatment of seed potatoes with PBZ at 0.1 mg L\(^{-1}\) resulted in smaller, more compact plants, which could be suitable for more densely planted in order to maximize plant population and increase economic return per unit of area.

Additional key words: Solanum tuberosum L.; gibberellin; plant regulator; tuberization.

RESUMEN
En condiciones de cultivo que favorezca el crecimiento de la parte aérea de la planta, la adopción de prácticas de manejo que reduzca el tamaño de las plantas puede ser una alternativa para aumentar el rendimiento de los tubérculos. El objetivo de este trabajo fue evaluar el efecto del paclobutrazol sobre el crecimiento vegetativo y la partición de la materia seca de la planta de papa cv. Markies cultivado en verano en el estado de Minas Gerais, Brasil. Los tratamientos fueron 0,1; 1,0; 10 y 100 mg L\(^{-1}\) de paclobutrazol (PBZ) aplicado a las semillas germinadas antes de plantar y un control tratado con agua. PBZ fue eficiente en la reducción de la altura de la planta. Los tratamientos con dosis de 10 y 100 mg L\(^{-1}\) de PBZ retrasaron la aparición de la parte aérea y el comienzo de la tuberización de la planta. PBZ a 0,1 mg L\(^{-1}\) redujo la longitud del tallo en un 18%, pero no difirió con el control en relación al contenido de masa fresca y
sec, la producción total, la gravedad específica y el contenido de almidón de los tubérculos. El tratamiento de tubérculos de papa con PBZ a 0,1 mg L\(^{-1}\) presentan plantas más pequeñas y compactas, que podrían ser adecuadas para una plantación más densa para maximizar la población de plantas y aumentar el rendimiento económico por unidad de área.

**Palabras clave adicionales:** *Solanum tuberosum* L.; giberelina; regulador vegetal; tuberización.

**INTRODUCTION**

With high biological value protein, the potato is considered one of the most nutritious food sources for man, being the fourth most consumed staple food in the world (ABBA, 2019a). Although in most of the countries it is consumed fresh, the potato is also directed for processing as frozen pre fried or dehydrated products, among other derivatives.

The consumption of industrialized potatoes in Brazil has increased significantly in recent years (Evangelista *et al*., 2011), especially following frozen pre-fried French fries. Good quality tubers are of fundamental importance for the processing industry, requiring high percentage of dry matter and starch, which favor the frying yield, providing less oil retention, guaranteeing the crispness and texture of the final product (Fernandes *et al*., 2010).

The lack of raw material in adequate quantity and quality has led to the search for new potato cultivars, with high quality for processing adapted to the brazilian climate conditions (Muller *et al*., 2009), and satisfy the characteristics required by the consumer market. Recently, the cultivar Markies, which presents tubers with characteristics similar to the frying cultivar Asterix (Fernandes *et al*., 2010; Evangelista *et al*., 2011), began to be cultivated in Brazil in significantly areas and happened to be one of the five top cultivars of processing potato planted in the country (ABBA, 2019b).

The State of Minas Gerais stands out as the main national producer of potatoes, participating with 32% of the total amount produced in the country (IBGE, 2019). Highland regions are preferred for potato cultivation, since they present mild temperatures and greater thermal amplitude between day and night. However, in the summer months, stem and leaf mass growth is favored by high temperatures, leading to reduced yield, increased fungal and bacterial diseases and tubers with low dry matter content. Thus, under cultivation conditions that favor the growth of the plant shoot, the adoption of management practices that reduce the size of plants can be an alternative to increase the yield of tubers. A practice that can be used to achieve better balance between the vegetative growth and the tuber is the use of plant growth retarding...
products, which act by inhibiting some steps of the gibberellin biosynthetic pathway (Rademacher, 2000).

The application of plant regulators in propagating organs such as seeds, bulbs, rhizomes, tubers and cuttings has numerous benefits compared to conventional procedures, being simple, low cost, reduces the concentration of the chemical to be used, the content of residues in the products is minimal or nul and low diffusion into the environment (Magnitskiy et al., 2006). Therefore, the application of regulators in seed potatoes would be an alternative to avoid the risks inherent to the use of these products in commercial potato production fields.

However, the implication of plant development for the use of these products in sprouted tubers, just before planting, is still unknown. Therefore, the objective of the present work was to evaluate the effect of paclobutrazol applied on the seed tubers on growth and dry matter partitioning of cv. Markies cultivated under summer conditions in the state of Minas Gerais.

MATERIAL AND METHODS

The experiment was carried out with cultivar Markies conducted at the Fazenda Água Santa, located in Perdizes, Minas Gerais (19°21’19” S and 47°16’58” W, with an altitude of 1,100 m), during the summer season of the Southeast region, between October 2015 and February 2016. According to the Köppen classification, the climate of the region is tropical de altitude (Cwb).

Thirty days before planting, the seed potatoes were removed from storage at 4°C and 85% relative humidity and placed at room temperature in the dark to induce spontaneous sprouting of the tubers. Seed potatoes were immersed for 30 min into 0.1, 1.0, 10 and 100 mg L⁻¹ paclobutrazol (PBZ).

The seed planting was done manually with spacing of 0.38 m between plant by 0.8 m between rows and planting depth of 0.12 m. The experimental plots consisted of 19.2 m², being 2.4 m wide and 8 m long and a longitudinal distance of 4 m between the plots was always maintained. The experiment was conducted in a split plot design, with the plots comprising the different concentrations of growth regulators and the subplots the plant evaluation times, in a completely randomized design with three replicates and each experimental unit consisted of two plants.

For the fertilization was applied 180 kg ha⁻¹ of N (MAP and ammonium nitrate), 420 kg ha⁻¹ of P₂O₅ (MAP) and 270 kg ha⁻¹ of K₂O (potassium chloride). Potassium chloride was applied in the pre-planting, the MAP in the planting and the potassium nitrate at 35 (ridge) and 65 d after planting. All treatments received micronutrient applications, via central pivot, throughout
the cycle.

During the growth period, the total precipitation was 1,133 mm and the average minimum and maximum monthly temperatures were 19 °C (ranging from 15.9 to 23°C) and 29°C (ranging from 19.8 a 37.1°C), respectively. The mean relative humidity was 77%, ranging from 53 to 94%. Solar radiation averaged 206 W m⁻².

The evaluations were carried out with 35 (Evaluation I), 50 (Evaluation II), 65 (Evaluation III), 80 (Evaluation IV) and 95 (Evaluation V) days after planting (DAP). Randomly selected plants were harvested from each treatment. The samples were divided into leaves, stems, tubers and roots/stolons. The fresh matter was determined immediately after harvest and the dry matter of each part of the plant was determined after drying in forced air circulation oven at 70°C for 5 d.

The dry matter partitioning was determined from the dry mass of each plant part and expressed as a percentage of total dry mass of the plant. The length of the longest stem, number and fresh mass of tubers were determined. The specific gravity was determined by the ratio between the tuber weight in air and the tuber weight in water (Maeda and Dip, 2000) and the dry matter content by the ratio between the dry and fresh mass of the tuber, expressed as a percentage. At 95 DAP, the desiccation of the shoot plants was performed by applying herbicide Diquat (400 g a.i. ha⁻¹). At 110 DAP, plants were harvested from the central rows of each plot to determine total yield.

The quantification of total soluble sugars of leaves and tubers was carried out according to the phenol-sulfuric acid method (Dubois et al., 1956). Reducing sugars were quantified according to the dinitrosalicylic acid (DNS) method (Gonçalves et al., 2010). The non-reducing sugar content was obtained by the difference between the total soluble sugar content and the reducing sugar content. For the quantification of starch, the method used was described by McCready et al. (1950).

The data were analyzed by analysis of variance (ANOVA) using the System of Statistical Analysis and Genetics of the (UFV, 2008). The means were compared by the Dunnett test at 5% probability. The data concerning the stem height and carbohydrate content of tubers was submitted to descriptive analysis.

RESULTS AND DISCUSSION

At 35 DAP, control plants and seed potato plants treated with the two lowest doses of paclobutrazo (PBZ) had already emerged, while those treated with 10 and 100 mg L⁻¹ of PBZ
only showed emergence of plants from 65 DAP (Tab. 1). In potato crop, it is desirable that before the planting of seed tubers, the dormancy be broken. The process of breaking dormancy and initiation of potato sprouting is triggered, among other factors, by the favorable internal balance of plant growth promoting regulators including auxins, cytokinins and gibberellins (Sonnewald and Sonnewald, 2014).

The delay in emergence of the treated plants with 10 and 100 mg L$^{-1}$ of PBZ may have occurred due to a drastic reduction in the content of endogenous gibberellins in the seed tubers, inhibiting the sprout growth for a long period. PBZ is a triazole that blocks the biosynthesis of gibberellic acid, reducing its endogenous concentration. The response of plants to PBZ varies according to the concentration, form of application, absorption and phenological stage in which the application was performed (Santos et al., 2004; Mabvongwe et al., 2016).

Seleguini et al. (2013) verified a linear reduction in the germination rate with the increase of PBZ doses applied to tomato seeds. According to Pill and Gunter (2001), the inhibitory effect of seed germination on PBZ-containing solutions may be associated with the rate of absorption of PBZ, causing toxicity to the embryo, with reduction in GA levels at values insufficient for germination and for seedling growth. According to Hung et al. (1992), the increase of concentration and exposure time of seeds to growth regulator contributed for the increase on product penetration in the seeds and consequent reduction of germination.

The percentage of dry matter (DM) into the leaves treated with 1.0 mg L$^{-1}$ of PBZ at 35 DAP, was significantly higher than the control, accounting for 81% of the total DM of the plant (Tab. 1). At 50 DAP, there was no difference among treatments in relation to the percentage of DM partition into the leaves. At 65 DAP, the plants treated with 1.0, 10 and 100 mg L$^{-1}$ of PBZ had the highest DM, while the control plants and those treated with PBZ 0.1 mg L$^{-1}$ provided the lowest percentages. In the last evaluation (95 DAP), all treatments showed decrease in the percentage of DM partitioned to the leaves, except for the two higher rates of PBZ, where initial growth delay was intense.
### Table 1. Partitioning of the dry matter (%) for each part of the potato and total dry matter (g), influenced by applications of paclobutrazol (PBZ) in the seed potatoes before of planting.

| PBZ doses (mg L⁻¹) | Leaves (%) | Roots (%) | Stems (%) | Tubers (%) | Total DM (g/plant) |
|-------------------|------------|-----------|-----------|------------|-------------------|
| **Evaluation I (35 DAP)** |            |           |           |            |                   |
| Control           | 77.24      | 11.75     | 11.01     | -          | 9.78              |
| 0.1               | 79.64      | 12.34     | 8.02*     | -          | 5.71*             |
| 1.0               | 81.18*     | 12.24     | 6.58*     | -          | 3.94*             |
| 10                | -          | -         | -         | -          |                   |
| 100               | -          | -         | -         | -          |                   |
| **CV (%)**        | 8.01       | 11.30     | 11.37     | -          | 11.50             |
| **Evaluation II (50 DAP)** |            |           |           |            |                   |
| Control           | 78.29      | 11.44     | 10.27     | -          | 33.58             |
| 0.1               | 80.01      | 12.01     | 7.98*     | -          | 18.05*            |
| 1.0               | 80.82      | 12.49     | 6.69*     | -          | 12.60*            |
| 10                | -          | -         | -         | -          |                   |
| 100               | -          | -         | -         | -          |                   |
| **CV (%)**        | 7.21       | 13.7      | 6.98      | -          | 14.85             |
| **Evaluation III (65 DAP)** |            |           |           |            |                   |
| Control           | 57.87      | 6.40      | 8.52      | 27.21      | 78.85             |
| 0.1               | 63.69      | 6.55      | 6.69*     | 23.07      | 62.62*            |
| 1.0               | 79.91*     | 11.31*    | 8.78*     | -          | 35.99*            |
| 10                | 79.38      | 12.84*    | 7.78*     | -          | 11.99*            |
| 100               | 78.60*     | 13.12*    | 8.29*     | -          | 8.56*             |
| **CV (%)**        | 7.94       | 14.7      | 19.6      | 8.97       | 10.23             |
| **Evaluation IV (80 DAP)** |            |           |           |            |                   |
| Control           | 42.42      | 5.59      | 6.63      | 45.36      | 129.48            |
| 0.1               | 48.59*     | 5.21*     | 6.57*     | 39.63      | 106.84*           |
| 1.0               | 61.36*     | 8.25*     | 6.49*     | 23.89*     | 76.38*            |
| 10                | 80.82      | 10.35*    | 8.83*     | -          | 28.95*            |
| 100               | 81.77*     | 9.74*     | 8.49*     | -          | 14.28*            |
| **CV (%)**        | 8.32       | 10.45     | 22.9      | 12.68      | 7.74              |
| **Evaluation V (95 DAP)** |            |           |           |            |                   |
| Control           | 34.75      | 4.26 b    | 5.96      | 55.03      | 151.48            |
| 0.1               | 39.59*     | 4.54*     | 5.57*     | 50.29      | 123.84*           |
| 1.0               | 49.03*     | 8.26*     | 5.49*     | 37.22*     | 95.38*            |
| 10                | 80.82      | 9.69*     | 9.49*     | -          | 35.61*            |
| 100               | 82.77*     | 9.07*     | 8.16*     | -          | 20.28*            |
| **CV (%)**        | 7.95       | 17.11     | 23.28     | 5.50       | 10.92             |

*ns non-significant; * significant (P≤0.05) with the control by the Dunnett test.

Partitioning of DM to roots at 35 and 50 DAP showed no significant difference between the treatments in which the plants had already emerged (Tab. 1). At 50 DAP, the roots of all treatments represented an average of 12% of the total DM of the whole plant. According to Tekalign and Hammes (2005), the root system represents around 4% of the total DM of the potato plant. However, such ratio may vary according to the cultivar and the growing conditions.
conditions. The subsequent evaluations at 65, 80 and 95 DAP, the seed potato plants treated with the 1.0, 10 and 100 mg L⁻¹ of PBZ showed a significant difference in relation to the control treatment, obtaining a higher percentage of DM partitioned to the roots. This effect may be a reflection of the reduction of the growth of the plant shoot, which possibly increases the availability of carbon directed to the root system.

Regarding the accumulation and distribution of DM to the stems, treatments with PBZ 0.1 and 1.0 mg L⁻¹ presented significant difference in relation to the control both evaluations at 35 and 50 DAP (Tab. 1). The treatments with 10 and 100 mg L⁻¹ of PBZ had the highest indexes of partition for the stems at 80 and 95 DAP when compared to the remaining treatments.

In this experiment, the beginning of the tuberization process started after 50 DAP, except for 1.0, 10 and 100 mg L⁻¹ of PBZ, which did not show any tuber formation. At 80 DAP, the plants treated with PBZ 1.0 mg L⁻¹ already had tubers, but with the lowest partition index of DM for the tubers compared to the control treatment. At 95 DAP, 55% of the total DM from the control plants were accumulated in the tubers, while in the treatment with PBZ 1.0 mg L⁻¹ the accumulation of DM was only 37.2%. The application of growth regulator PBZ on seed potatoes before planting did not increase the DM partition to the tubers in the bulking phase.

At the first stages of potato development, the preferential metabolic drains are the leaves and stems, and later the tubers with fast growth during the tuber bulking. Because of that, a high mobilizing capacity of the tubers caused marked reduction in the accumulation of dry matter, beginning at 65 DAP, for both the leaves and the stems (Tab. 1). In the treatments with 10 and 100 mg L⁻¹ of PBZ, this change was not noticed until the 95DAP due to the delay in the tuberization of these plants.

Based on the accumulations of DM in the whole plant, in the first evaluation, the control treatment plants had the highest DM contents, followed by lowest dose of the PBZ treatment, and treatment with PBZ 1.0 mg L⁻¹ (Tab. 1). In the evaluation III (65 DAP) it was possible to observe a slow initial growth of the plants treated with PBZ 10 and 100 mg L⁻¹, presenting a lower percentage of total DM in relation to the other treatments. In the last partition evaluation, the lowest percentage of DM accumulation in the whole plant was obtained in the treatment with the highest dose of PBZ (100 mg L⁻¹).

The control plants had longer main stem length compared to PBZ treated seed potatoes throughout the plant cycle (Fig. 1). The immersion of the sprouted seed before planting in solution containing 0.1; 1.0; 10 and 100 mg L⁻¹ of PBZ reduced the length of the stem by about 18; 25; 51 and 55%, in comparison to the control, respectively. Treatments of seed potato with
PBZ resulted in smaller, more compact plants, which could be suitable for more densely planted in order to maximize plant population and increase economic return per unit of land. Several studies, however, have indicated disadvantages of PBZ seed treatment, which include delay and reduction in the shoot emergence rate (Pasian and Bennett, 2001).

In tomato, the application of PBZ to seedlings influenced the stems length up to 15 d after transplanting, showing that the effect of the regulator can be limited during the culture cycle (Ferreira et al., 2017). PBZ at 0.250 L ha⁻¹ applied via spraying at 35 d after planting was efficient in reducing the potato plant height by 20% compared to control plants (Araújo et al., 2019).

According to Fletcher et al. (2000), the reduction in plant height induced by PBZ is linked to the inhibition of the conversion of ent-kaurene to ent-kaurenoic acid, resulting in reduction in gibberellic acid levels with consequent decrease in elongation rate and cell division. López et al. (2011) observed that the spraying of the growth regulators paclobutrazol and uniconazole in potato leaves, were more effective in reducing the shoot growth of the potato plants compared to the cycocell growth regulator. Fagan et al. (2019) attributed the effects to the different modes of action of the compounds in gibberellin biosynthesis. Trinexapac-ethyl is an acyclcyclohexanoedione, which in poaceae species, such as wheat and rye, causes a reduction in the length of internodes and, consequently, in plant height. However, in dicotyledons this inhibition is not so strong, thus showing selectivity of trinexapac-ethyl by species of the family Poaceae (Rademacher, 2000).

![Figure 1. Length of longest stem of plants from potato seeds treated with paclobutrazol (PBZ) over the days after planting. The vertical bars represent the standard error of the mean.](image-url)
Treatments with PBZ doses significantly decreased the number of tubers per plant when compared to the control (Tab. 2). The average of PBZ 10 and 100 mg L\(^{-1}\) treatments was 5 tubers per plant, while for the control was 7.33. Results obtained by other authors, also verified that PBZ, applied in the form of foliar spraying, reduced the number of tubers of plants (Kianmehr et al., 2012; Mabvongwe et al., 2016).

Treatments 1.0, 10 and 100 mg L\(^{-1}\) of PBZ, significantly reduced the fresh and dry mass of the tubers per plant, and the total production of tubers being 39.2; 73.2 and 79.0% when compared to the control, respectively (Tab. 2). There was significant reduction of the specific gravity in the tubers with 10 and 100 mg L\(^{-1}\) of PBZ compared to control and the remaining treatments (Tab. 2). These PBZ treatments also delayed the emergence of plants and in the beginning of the tuberization. At the final harvest, at 110 DAP, the tubers from 0 and 100 mg L\(^{-1}\) of PBZ rates were still in the initial filling stage, which led to the reduction of specific gravity compared to the other treatments.

### Table 2. Number of tubers, fresh matter mass, dry matter mass, total yield and specific gravity of potato tubers influenced by applications of paclobutrazol (PBZ).

| TBZ doses | Tubers number | Tuber fresh mass (g plant\(^{-1}\)) | Tuber dry mass (g plant\(^{-1}\)) | Total yield (Mg ha\(^{-1}\)) | Specific gravity (g cm\(^{-3}\)) |
|-----------|---------------|-----------------------------------|-------------------------------|-----------------------------|-------------------------------|
| Control   | 7.33          | 654.16                            | 104.40                        | 23.54                       | 1.0581                        |
| 0.1       | 6.00*         | 622.93\(^{ns}\)                   | 90.83\(^{ns}\)                | 22.42\(^{ns}\)             | 1.0564\(^{ns}\)              |
| 1.0       | 5.67*         | 397.94*                           | 58.01*                        | 14.32*                      | 1.0560\(^{ns}\)             |
| 10        | 5.00*         | 175.62*                           | 25.33*                        | 6.32*                       | 1.0540*                      |
| 100       | 5.00*         | 137.44*                           | 19.61*                        | 4.95*                       | 1.0534*                      |
| CV (%)    | 9.5           | 8.5                               | 9.2                           | 13.6                        | 0.9                           |

\(^{ns}\) non-significant; * significant (P\(\leq\)0.05) with the control by the Dunnett test.

Regardless the treatment, the predominant soluble sugars present in the tubers was non-reducing. In all treatments, there was a decrease in non-reducing sugars (NRS) content over time (Fig. 3C). At the end of the experiment (110 DAP), treatments with the two lower doses of PBZ did not differ from the control.

Reducing sugars (RS) content decreased during the evaluation period for all treatments, except for PBZ 0.1 mg L\(^{-1}\), where at 85 DAP an increase of this sugar was observed, followed by subsequent decrease (Figure 3B). The two highest doses of PBZ presented higher levels of RS at 95 and 110 DAP, which can be explained by the delay in tuberization and consequent maturation of the tubers. In the final harvest (110 DAP), the tubers of the treatments with 10 and 100 mg L\(^{-1}\) of PBZ presented high content of reducing sugars, with 0.2% and 0.18%, respectively (Fig. 3C).
High accumulation of reducing sugars lead to the reaction with free amino acids, called the Maillard reaction, or non-enzymatic browning (Low et al., 1989), resulting in products with brown coloration. After frying for 3 min at 180 °C, the French fries developed excessive brown color (data not shown) when the seed tubers were treated with 10 and 100 mg L⁻¹ of PBZ.

![Figure 3](link)

Figure 3. The content of total soluble sugars, reducing sugars, non-reducing sugars and starch in tubers of potato seed plants treated with paclobutrazol (PBZ) (A, B, C and D), respectively, according to the days after planting. The vertical bars represent the standard error of the mean.

Tuber starch content at 80 DAP decreased when treated 0.1 and 1.0 mg L⁻¹ of PBZ, followed by an increase until the end of the experiment (Fig. 3D). This decline may have occurred due to a momentary dilution of the starch content due to the increase in the water content of the tubers, since on the date of this evaluation a high volume of water was reported in the soil, due to the heavy rains.

At the final harvest, the two highest doses of PBZ had lower content of starch (Fig. 3C), indicating the delayed tuber development caused by the 10 and 100 mg L⁻¹ of PBZ. The reduction in the total soluble carbohydrate content during the cycle coincided with the increase
in the starch content, indicating the beginning of tuber maturation. Lewis et al. (1994) also observed reduction in total sugar levels in developing tubers, indicating an increase in the rate of starch synthesis.

CONCLUSIONS

The two higher doses (100 and 10 mg L⁻¹) of PBZ delayed the emergence of shoot and the beginning of tuberization. Treatments of seed potatoes with PBZ at 0.1 mg L⁻¹ resulted in smaller, more compact plants, which could be suitable for more densely planted in order to maximize plant population and increase economic return per unit of land.

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BIBLIOGRAPHIC REFERENCES

ABBA, Associação Brasileira de Batata. 2019a. A batata. In: http://www.abbabatabrasileira.com.br/site/?id_BAT=3; consulted: August, 2019.

ABBA, Associação Brasileira da Batata. 2019b. Variedades. In: http://www.abbabatabrasileira.com.br/site/?id_BAT=3; consulted: August, 2019.

Araújo, F.F., T.P. Silva, M.N.S. Santos, L.C. Costa, and F.L. Finger. 2019. Morphophysiological and agronomic characteristics of potato 'Markies' treated with gibberellin inhibitors. Acta Hortic. 1251, 153-158. Doi: https://doi.org/10.17660/ActaHortic.2019.1251.22
Dubois, M., K.A. Gilles, J.K. Hamilton, P.A. Rebers, and F. Smith. 1956. Colorimetric method for determination of sugars and related substances. Anal. Chem. 28, 350-356. Doi: https://doi.org/10.1021/ac60111a017

Evangelista, R.M., I. Nardin, A.M. Fernandes, and R.P. Soratto. 2011. Qualidade nutricional e esverdeamento pós-colheita de tubérculos de cultivares de batata. Pesq. Agropec. Bras. 46(8), 953-960. Doi: https://doi.org/10.1590/1678-4499.0330

Fagan, E.B., E.O. Ono, J.D. Rodrigues, A. Chalfun Júnior, and D. Dourado Neto. 2019. Fisiologia vegetal: reguladores vegetais. Andrei, Sao Paulo, Brazil.

Ferreira, N., E. Vendruscolo, A. Seleguini, W. Dourado, C. Benett, and A. Nascimento, 2017. Crescimento, produção e qualidade de frutos de tomateiro em cultivo adensado com uso de paclobutrazol. Rev. Colomb. Cienc. Hortic. 11(1), 72-79. Doi: https://doi.org/10.17584/rcch.2017v11i1.5690

Fernandes, A.M., R.P. Soratto, R.M. Evangelista, and I. Nardin. 2010. Qualidade físico-química e de fritura de tubérculos de cultivares de batata na safa de inverno. Hortic. Bras. 28, 299-304. Doi: https://doi.org/10.1590/S0102-05362010000300010

Fletcher, R.A., A. Gilley, N. Sankhla, and T. Davis. 2000. Triazoles as plant growth regulators and stress protectants. Hort. Rev. 24, 55-138. Doi: https://doi.org/10.1002/9780470650776.ch3

Gonçalves, C., M.R. Rodrigues-Jasso, N. Gomes, J.A. Teixeira, and I. Belo. 2010. Adaptation of dinitrosalicylic acid method to microtiter plates. Anal. Methods 2, 2046-2048. Doi: https://doi.org/10.1039/c0ay00525h

Hung, P.E., V.A. Fritz, and L. Waters. 1992. Infusion of shrunken-2 sweet corn seed with organic solvents: effects on germination and vigor. Hortscience 27(5), 467-470. Doi: https://doi.org/10.21273/HORTSC1.27.5.467
IBGE, Instituto Brasileiro de Geografia e Estatística. 2019. Produção Agrícola Municipal. In: http://www.sidra.ibge.gov.br/bda/pesquisas/pam/default.asp; consulted: August, 2019.

Kianmehr, B., M. Otroshy, M. Parsa, M.N. Mohallati, and K. Moradi. 2012. Effect of plant growth regulation during in vitro phase on potato minituber production. Int. J. Agric. Crop Sci. 4, 1060-1067.

Lewis, C.E., J.E. Lancaster, P. Meredith, and J.R.L. Walker. 1994. Starch metabolism during growth and storage of tubers of two New Zealand potato cultivars. New Zeal. J. Crop Hort. Sci. 22(3), 295-304. Doi: https://doi.org/10.1080/01140671.1994.9513838

López, R.F., F.S.D. Castilho, J.E.R. Pérez, R.M. Aguilar, M.T.C. León, and H.L. Saldaña. 2011. Paclobutrazol, unizonazol y cycocel en la producción de tubérculo-semilla de papa en cultivo hidropónico. Rev. Chapingo Ser. Hortic. 17, 173-182.

Low, N., B. Jiang, and S. Dokhant. 1989. Reduction of glucose content in potatoes with glucose oxidase. J. Food Sci. 54, 118-121. Doi: https://doi.org/10.1111/j.1365-2621.1989.tb08581.x

Mabvongwe, O., B.T. Manenji, M. Gwazane, and M. Chandiposha. 2016. The effect of paclobutrazol application time and variety on growth, yield, and quality of potato (Solanum tuberosum L.). Adv. Agric. 5. Doi: https://doi.org/10.1155/2016/1585463

Maeda, M. and T.M. Dip. 2000. Curvas de crescimento mássica de água x peso específico em vegetais in natura - otimização de processos industriais pela seleção via teste de matéria-prima. Cienc. Tecnol. Alime. 20(3), 309-313. Doi: https://doi.org/10.1590/S0101-2061200000300006

Magnitskiy, V.S., C.C. Pasian, M.A. Bennett, and J.D. Metzger. 2006. Effects of soaking cucumber and tomato seeds in paclobutrazol solutions on fruit weight, fruit size and paclobutrazol level in fruits. HortScience 41(6), 1446-1448. Doi: https://doi.org/10.21273/HORTSCI.41.6.1446
Mcready, R.M., J. Guggolz, and H.S. Wens. 1950. Determination of starch and amylase in vegetables. Anal. Chem. 22, 1156-1158. Doi: https://doi.org/10.1021/ac60045a016

Muller, D.R., D.A. Bisognin, J.L. Andriolo, G.R.M. Junior, and F.S. Gnocato. 2009. Expressão dos caracteres e seleção de clones de batata nas condições de cultivo de primavera e outono. Cienc. Rural 39, 1327-1334. Doi: https://doi.org/10.1590/S0103-84782009005000078

Pasian, C.C. and M. Bennett. 2001. Paclobutrazol soaked marigold, geranium, and tomato seeds produce short seedlings. HortScience 36, 721-731. Doi: https://doi.org/10.21273/HORTSCI.36.4.721

Pill, W.G. and J.A. Gunter. 2001. Emergence and shoot growth of cosmos and marigold from paclobutrazol treated seed. J. Environ. Hort. 19(1), 11-14.

Rademacher, W. 2000. Growth retardants: effects on gibberellin biosynthesis and other metabolic pathways. Annu. Rev. Plant Physiol. 51, 501-531. Doi: https://doi.org/10.1146/annurev.arplant.51.1.501

Santos, C.H., A.E. Klar, H. Grassi Filho, J.D. Rodrigues, and F.C. Pierre. 2004. Indução do florescimento e crescimento de tangerineira poncã (Citrus reticulata Blanco) em função da irrigação e da aplicação de paclobutrazol. Rev. Bras. Frutic. 26(1), 8-12. Doi: https://doi.org/10.1590/S0100-29452004000100005

Seleguini, A., M.J.A. Faria-Júnior, K.S.S. Benett, O.L. Lemos, and S. Seno. 2013. Estratégias para produção de mudas de tomateiro utilizando paclobutrazol. Semin. Cienc. Agrar. 34, 539-548. Doi: https://doi.org/10.5433/1679-0359.2013v34n2p539

Sonnewald, S. and U. Sonnewald. 2014. Regulation of potato tuber sprouting. Planta 239, 27-38. Doi: https://doi.org/10.1007/s00425-013-1968-z

Tekalign, T. and P.S. Hammes. 2005. Growth responses of potato (Solanum tuberosum) grown in a hot tropical lowland to applied paclobutrazol: 1. Shoot attributes, assimilate
Araujo, F.F., M.N.S. Santos, N.O. Araújo, T.P. Silva, L.C. Costa, F.L. Finger. 2020. Growth and dry matter partitioning of potato influenced by paclobutrazol applied to seed tuber. Revista Colombiana de Ciencias Hortícolas 14(1). Doi: https://doi.org/10.17584/rcch.2020v14i1.10357

production and allocation. New Zeal. J. Crop Hort. Sci. 33(1), 35-42. Doi: https://doi.org/10.1080/01140671.2005.9514328

UFV, Universidade Federal de Viçosa. 2008. SAEG, Sistema de análises estatísticas e genéticas v 9.1 (CD-ROM). Viçosa, Brazil.