Comunicata Scientiae
Horticultural Journal

ORIGINAL ARTICLE
published: 31 Janeiro 2024
https://doi.org/10.14295/CS.v15.4108

Tolerance of pineapple cultivars to natural flowering induction in the state of Mato Grosso

Debora Sarana Ortolan Arantes[1], Willian Krause[1], Angélica Padilha de Freitas[1], Dayane Castro Silva[1]*, Rivanildo Dallacort[1], William Fenner[1]

1Universidade do Estado de Mato Grosso, Tangará da Serra-MT, Brazil
*Corresponding author, e-mail: daykastro@gmail.com

Abstract

Natural flowering in pineapple crops can cause significant economic losses to growers, resulting in uneven fruiting, which hinders phytosanitary operations and the scaling of fruit harvest. The objective of this work was to evaluate the tolerance of eight pineapple cultivars to natural flowering induction in Tangara da Serra, Mato Grosso, Brazil. The cultivars BRS-Ajuba, BRS-Imperial, BRS-Vitoria, Gigante-de-Tarauaca, IAC-Fantastico, Jupi, Perola, and Smooth-Cayenne were evaluated. Planting was carried out in May of 2018, in a randomized block design, with five replications and 20 plants per plot. Plant height, D-leaf length, and percentage of induced plants were evaluated. The surveying period of plants naturally induced was between May and September 2019. In this period, the plants were between 12 and 16 months of age, with adequate D-leaf lengths and plant heights for the occurrence of flowering induction. There were days with night-time temperatures below 15 °C; the lowest photoperiod was in June. The cultivars Smooth-Cayenne, BRS-Imperial, and IAC-Fantastico were tolerant to the natural induction, which resulted in uneven fruiting, causing losses to growers.

Keywords: *Ananas comosus var. comosus*, flowering induction, breeding, temperature

Introduction

Pineapple (*Ananas comosus* (L.) Merr var. *comosus*) is a Bromeliaceae grown in tropical and subtropical regions (Chen et al., 2016). The production in Brazil reached 2.4 million Mg in an area of 65,049 hectares in 2020, making it the third largest pineapple producing country in the world (Fao, 2020). Natural flowering induction (NFI) is among factors that affect pineapple crops (Wang et al., 2007); it can cause significant economic losses to growers because of uneven flowering and fruiting, requiring multiple phytosanitary operations in the same parcel and harvests (Liu et al., 2020). In addition, it affects the scaling of fruit harvest and, when natural induction occurs in plants with sizes lower than the ideal for flowering, they will result in small fruits.

Several factors are responsible for the occurrence of NFI, such as temperature, photoperiod, solar radiation, sensitivity of the cultivar, plant size, and other factors that lead to NFI (Sanewski & Bartholomew, 2018). Natural flowering occurs in the winter, since pineapple is a short-day plant; the decrease in photoperiod and/or temperature induces the apical bud to produce an inflorescence instead of leaves (Ricce et al., 2014).

According to (Friend, 1981), natural induction occurs earlier in environments that present mean day/night temperatures of 30/20 °C, under an 8-hour photoperiod. Moreover, (Bartholomew, 2013) reported that photoperiods lower than 11 hours and 30 minutes are more likely to induce natural flowering, and some data denote that NFI occurs in response to increases in ethylene production in the stem apical tissue and in the white basal tissue of young leaves.

Early flowering induction using artificial flowering inducers and the use of seedlings with adequate size are alternatives for the control of natural flowering, thus avoiding early flowering and production losses to the

Received: 13 October 2022
Accepted: 20 March 2023

grower due to lower size and weight of fruits (Pereira et al., 2015).

D-leaves with weights equal to or higher than 80 g and lengths of at least 1.0 m are recommended to obtain quality fruits for the cultivar Perola. In this case, the occurrence of NFI may provide the conditions to produce large-size fruits (Oliveira, 2009). However, the occurrence of NFI may result in small fruits when the plant has a small size and, consequently, low prices. In this context, the objective of this work was to evaluate the tolerance of pineapple cultivars to NFI in Tangara da Serra, Mato Grosso, Brazil.

Material and methods

The experiment was carried out at the Mato Grosso State University (UNEMAT), in the municipality of Tangara da Serra, state of Mato Grosso, Brazil (14°37'55"S, 57°28'05"W, and altitude of 321 m). The region presents a mean annual rainfall depth of 1.830 mm and mean temperatures between 24.4 and 26.1 °C, with two well-defined seasons: a rainy season between October and April and a dry season between May and September (Martins et al., 2010). The soil of the area was classified as a Typic Hapludox (Latossolo Vermelho distrofico, according to the Brazilian Soil Classification System; Santos et al., 2018).

The soil was prepared with plowing, harrowing, and opening of furrows. Based on the analysis of the 0–20 cm layer, the soil presented the following results: pH (water) of 5.2; 1.48 mg dm^{-3} of P; 80 mg dm^{-3} of K; 0.12 cmolc dm^{-3} of Al; 0.85 cmolc dm^{-3} of Ca; 0.29 cmolc dm^{-3} of Mg; 3.75 cmolc dm^{-3} of H+Al; 1.3 cmolc dm^{-3} of sum of bases; 5.05 of cation exchange capacity at pH 7.0; 25.75% of base saturation; and 12 g dm^{-3} of organic matter. Liming and soil fertilizer application at planting and topdressing were carried out following recommendations for pineapple crops (Embrapa, 2021).

The planting was carried out in May 2018, in double rows with spacing of 1.2×0.4×0.4 m. The seedlings used were suckers with approximately 35 cm length, obtained from the active germplasm bank of the UNEMAT. The cultivars BRS-Ajuba, BRS-Imperial, BRS-Vitoria, Gigante-de-Tarauaca, IAC-Fantastico, Jupi, Perola, and Smooth-Cayenne were evaluated. A randomized block experimental design was used, with five replications and 20 plants per plot.

The control of weeds was carried out by manual weeding and application of herbicides recommended for the crop. Irrigation was carried out three times a week. The surveying of number of plants naturally induced was carried out weekly from May 01 to September 18, 2019, which is the period when the lowest temperatures and photoperiod occur (Martins et al., 2010). The induced plants were identified upon observations of emergence of the shoot floral apex. This surveying was used to calculate the accumulated percentage of naturally induced plants. The other variables evaluated were: plant height (cm), measured from the ground to the highest leaf at natural position of the plant; and D-leaf length (cm), measured with the aid of a tape ruler, from the leaf base to the tip (Queiroz et al., 2003).

The data of percentage of induced plants, plant height, and D-leaf length were subjected to analysis of variance by the F test, using the R 4.0.0 program (R Core Team, 2017), and the means were grouped by the Scott-Knott test ($p<0.05$).

Weather data were collected through an automatic meteorological station (Campbell Scientific) installed next to the experiment, which is linked to the Climate Laboratory of the Geoprocessing and Remote Sensing Technology Center. The meteorological station was equipped with a Datalogger (CR1000) that provides readings every 20 minutes and hourly means, using sensors of temperature and relative air humidity (CS215), barometer (CS106), pyranometer (CMP3), anemometer (03002-R.M.), and a pluviometer (TB4 rain gauge). The data collected were transformed to daily means and tabulated in spreadsheets for data analysis, considering the minimum temperatures (°C) and global solar radiation (MJ m^2 d^{-1}) from April to September 2019.

The photoperiod was calculated for each day of the year, considering the local latitude (-14.65°) and then the crop period was selected. The solar declination was determined according to (Cooper, 1969), as used by (Vianello and Alves, 2000), based on the equation: $\delta = 23.45 \text{ sen}[360/365 (284+n)]$, where n is the Julian day. The solar day duration (H, expressed in degrees) was then determined, through the equation $\cos H = -tg\Phi * tg\delta$, where Φ is the local latitude (decimal) and δ is the solar declination (degrees). The photoperiod (N) was then determined according to the equation $N = 2H/15'$ where N is expressed in hours (decimal).

Results and discussion

The change from the vegetative to the reproduction stage in pineapple crops is an essential step in the plant cycle. Flowering is controlled by several endogenous and exogenous signals, including photoperiod, temperature, and plant age (Song et al., 2013; Van Doorn & Kamdee, 2014). In the period of surveying plants with natural flowering induction (NFI), there were days with night-time temperatures below

15 °C (**Figure 1**): 3 of them in May, 2 in June, 8 in July, and 5 in August. In September, there was no record of temperatures below 15 °C. Temperatures below 15 °C, mainly night-time, stimulate NFI in pineapple plants (Bartholomew & Sanewski, 2018).

(Gowing, 1961) evaluated the cultivar Smooth-Cayenne, comparing night-time temperatures of 15, 23, and 26°C, and found that the night-time temperature of 15 °C induced the flowering when combined with short-day periods. Although the cultivar Smooth-Cayenne

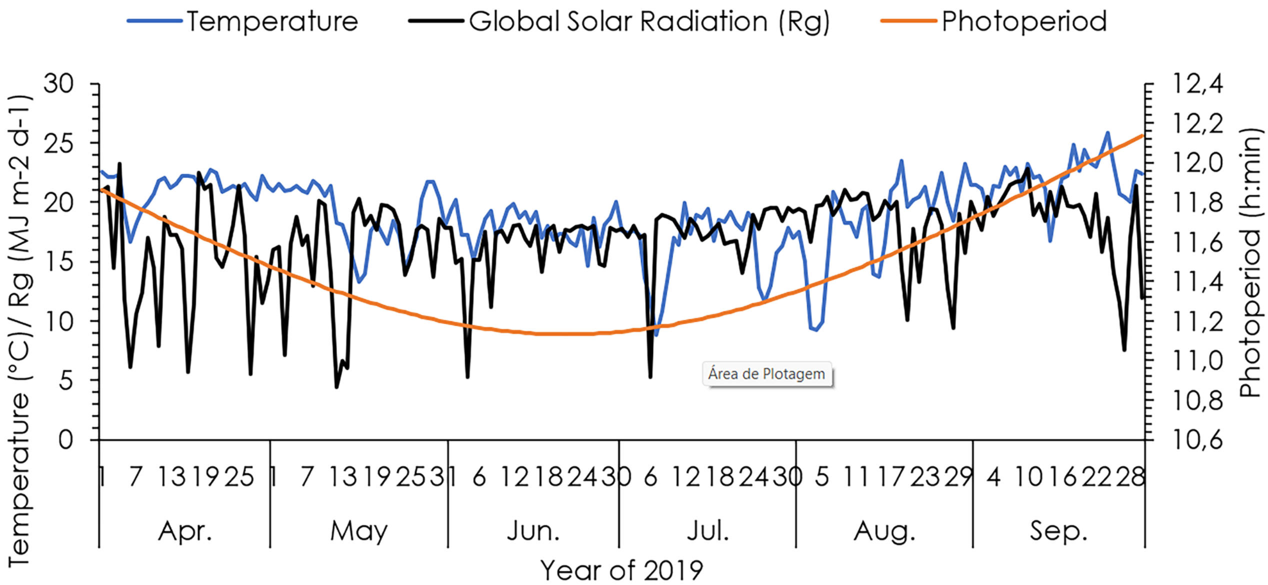

Figure 1. Minimum air temperatures, global solar radiation, and photoperiod between April and September 2019. Tangara da Serra, MT, Brazil.

In addition to temperature, photoperiod also varied during the evaluation period; it was 11 hours and 19 minutes in May, presented the lowest value in June (11 hours and 09 minutes), and reached 11 hours and 55 minutes in September (Figure 1). Considering regions above and below the Equator, NFI in the cultivars MD-2 and CO-2 can occur at any time after the photoperiod decrease to 11 hours (Bartholomew, 2013). The photoperiod regulates the plant response to day length and is especially important for pineapple plants because of its potential implications for NFI (Li et al., 2016).

Changes in photoperiod and temperature are sensed by different plant organs. Photoperiod is sensed by leaves and temperature is sensed by all the plant parts, mainly by the stem apex (Bernier et al., 1993). Considering pineapple plants, it is required that the plant has at least one leaf so that the flowering stimulus can be sensed and pass to the stem apex. Despite photoperiod is sensed by leaves, the morphological changes that cause the transition for flower formation occur in the stem apex, which indicates a transmission of some signal from the leaf to the stem apex, resulting in floral stimulus (Castro & Vieira, 2001). This signal stimulates the production of ethylene in the plant leaf tissue and in the stem apex (Trusov & Botella, 2006).

is considered a short-day plant, cold temperatures increase the flowering stimulus, which is also true for other cultivars. This high correlation between photoperiod and temperature hinders the establishment of relative importance in field studies (Bartholomew & Sanewski, 2018).

The mean global solar radiation in the evaluation period was 16.95 MJ m^{-2} d^{-1}, with maximum of 18.53 MJ m^{-2} d^{-1} in September and minimum of 15.33 MJ m^{-2} d^{-1} in April (Figure 1). It showed a variation percentage of +9.32% for the maximum and -9.55% for the minimum global solar radiation, compared to the mean of the period. There is little information showing that solar radiation direct affects NFI in pineapple plants. However, combined with short photoperiods and low temperatures, it contributes to flowering induction (Bartholomew & Sanewski, 2018).

In addition to favorable climate characteristics, plants with adequate vegetative conditions are required for the occurrence of NFI in pineapple plants. The evaluation period of natural induction occurred when the plants were between 12 and 16 months of age, which is considered an adequate age for flowering. The recommended age for flowering induction in pineapple is 8 to 12 months after planting (Ledo et al., 2004).

Regarding plant height, the cultivars BRS-Ajuba, Gigante-de-Tarauaca, Jupi, and Perola presented higher results than the other cultivars, with means of 123.94, 119.98, 119.36, and 114.78 cm, respectively (**Table 1**). The lowest plant heights were found for the cultivars BRS-Vitoria, IAC-Fantastico, and BRS-Imperial. The lowest plant height and D-leaf length (Table 1) of the cultivar Smooth-Cayenne is due to its genotype; the cultivars BRS-Imperial, BRS-Vitoria, and IAC-Fantastico have the cultivar Smooth-Cayenne as parental, thus, they presented similar dynamics (Bartholomew & Sanewski, 2018). In practice, studies have found that even small plants present some capacity to be induced under favorable stimuli, natural or artificial (Cunha, 1989).

Table 1. Means for plant height (PH), D-leaf length (DLL), and percentage of plants with natural flowering induction (NFI%) of eight pineapple cultivars. Tangara da Serra, MT, Brazil, 2019

Cultivars	PH (cm)	DLL (cm)	NFI%
Gigante-de-Tarauaca	119.98a[1/]	113.30a	100a
Perola	114.78a	107.54b	100a
Jupi	119.36a	103.36b	100a
BRS-Ajuba	123.94a	88.42c	32b
BRS-Vitoria	90.98b	77.82d	32b
IAC-Fantastico	91.88b	67.38e	8c
BRS-Imperial	96.39b	73.30d	0c
Smooth-Cayenne	70.36c	53.88f	0c

[1/] Means followed by the same letter in the columns are not different from each other by the Scott-Knott test ($p<0.05$).

Therefore, there was favorable climate conditions (temperature, photoperiod, and solar radiation) to NFI, as well as age, plant height, and D-leaf length (Table 1). However, there was a significant difference between the cultivars in percentage of plants naturally induced (NFI%) (Table 1). The cultivars Gigante-de-Tarauaca, Jupi, and Perola presented 100%, BRS-Ajuba and BRS-Vitoria presented 32%, and IAC-Fantastico presented 8% naturally induced plants. BRS-Imperial and Smooth-Cayenne presented 0% naturally induced plants and were considered the most tolerant to NFI. These cultivars were classified, from the most to the least susceptible to NFI, as follows: Gigante-de-Tarauaca = Jupi = Perola > BRS-Ajuba = BRS-Vitoria > IAC-Fantastico = BRS-Imperial = Smooth-Cayenne. (Bartholomew and Sanewski, 2018) found a variation in sensitivity of cultivars to NFI and classified them, from the most to the least susceptible to NFI, as MD-2 > CO-2 > Smooth-Cayenne; Queen, Perola, and Tainung 17 were more sensitive to NFI than Smooth-Cayenne.

This difference denotes the genetic variability between cultivars regarding NFI. Variability is the main factor for the development of plant breeding programs. Thus, breeding programs can be carried out to obtain genotypes tolerant to NFI. It has been the focus of some breeding programs in the world, as by example, that developed by the Dole Food Company, which produced the pineapple cultivar Dole-14 through conventional genetic improvement methods; this cultivar has low sensitive to NFI (Young & Gonzales, 2010).

In some cases, biotechnology has been used for obtaining characters that are difficult or impossible to be naturally obtained through conventional genetic improvement methods. In Australia, pineapple plants were transformed genetically for producing less 1-amino-cyclopropane-1-carboxylate synthase (ACC synthase) (AcAcs2), which is the gene responsible for synthesis of ethylene in these plants; field tests showed a delay in natural flowering of pineapple plants (Trusov & Botella, 2006). The Del Monte Fresh Produce Company developed a MD-2 genetically transformed pineapple plant and named it Rose; its sensitivity to NFI caused by climatic factors decreased in field conditions (Firoozabady and Young, 2013).

The cultivars with the lowest NFI% were BRS-Imperial, BRS-Ajuba, BRS-Vitoria, and IAC-Fantastico, which have the cultivar Smooth-Cayenne as one of the parents. This indicates that this characteristic can be inherited with variations in degree of tolerance to NFI; in the present study, they showed 68% to 100% tolerance to NFI.

The different results found for the cultivars regarding tolerance to NFI indicate that this characteristic is controlled by several genes (. Liu and Fan, 2016) identified a 13-gene complex that affects the control of ethylene synthesis, spread through several pathways, denoting a complex network for control of flowering in pineapple. Thus, it raised the need for studies and advances in molecular biology that assist in understanding molecular processes and pathways associated to flowering.

The NFI resulted in uneven flowering (**Table 2**) and, consequently, uneven harvest. Perola, the most grown pineapple cultivar in Brazil, presented high susceptibility to NFI, with flowering distributed over a 10-week period. This unevenness prevents the grower to establish a harvest scale to meet the market demand. In addition, it affects the phytosanitary management of the main disease that attacks pineapple plants (fusariosis) and increases production costs. The occurrence of simultaneous floral differentiation in all plants of the parcel is desirable in pineapple plantations (Carvalho et al., 2005). Therefore, under the conditions of the state of Mato Grosso, NFI can be reduced by managing the seedling size and planting season. Large seedlings can be planted at the beginning of the rainy period for the seedlings to reach adequate

Table 2. Percentage of plants naturally induced in eight pineapple cultivars evaluated from May to September 2019. Tangara da Serra, MT, Brazil

Date (2019)	Cultivars							
	Gigante de Tarauaca	Perola	Jupi	BRS Imperial	BRS Ajuba	BRS Vitoria	IAC Fantastico	Smooth Cayenne
May 26	0	4	3	0	0	0	0	0
Jun 05	0	5	5	0	0	0	0	0
Jun 12	0	7	13	0	0	0	0	0
Jun 19	0	9	34	0	0	0	0	0
Jun 26	18	30	61	0	0	15	0	0
Jul 03	62	66	89	0	0	18	0	0
Jul 10	100	84	99	0	1	21	2	0
Jul 17	100	84	100	0	8	23	2	0
Jul 24	100	84	100	0	12	26	4	0
Jul 31	100	100	100	0	13	27	4	0
Aug 07	100	100	100	0	13	27	4	0
Aug 14	100	100	100	0	13	27	4	0
Aug 21	100	100	100	0	13	27	4	0
Aug 28	100	100	100	0	13	27	4	0
Sep 04	100	100	100	0	28	31	8	0
Sep 11	100	100	100	0	32	32	8	0
Sep 18	100	100	100	0	32	32	8	0

size for artificial flowering induction before the favorable period for natural floral differentiation, and small seedlings can be planted at the end of the rainy period for the seedlings to pass through the natural induction period without reaching enough size to respond to natural flowering stimuli.

Conclusions

The cultivars Smooth Cayenne, BRS Imperial, and IAC Fantastico were tolerant and can be used in pineapple breeding programs focused on tolerance to natural flowering induction.

Natural flowering induction results in uneven flowering and fruiting; the cultivars Perola and Jupi are the most susceptible to this induction.

Acknowledgements

This work was carried out with the support of the Brazilian Coordination for the Improvement of Higher Education Personnel (CAPES; Financing Code 001).

References

Bartholomew, D.P. 2013. History and perspectives on the role of ethylene in pineapple flowering. *Acta Horticulturae* 1042: 269-284.

Bernier, G., Havelange, A., Houssa, C., Petitjean, A., Lejeune, P. 1993. Physiological signals that induce flowering. *The Planct Cell* 5: 1147-1155.

Carvalho, S.L.C.D., Neves, C.S.V.J., Bürkle, R., Marur, C.J. 2005. Épocas de indução floral e soma térmica do período do florescimento à colheita de abacaxi 'Smooth Cayenne'. *Revista Brasileira de Fruticultura* 27: 430-433.

Castro, P.R.C., Vieira, E.L. 2001. *Aplicações de reguladores vegetais na agricultura tropical.* Embrapa, Guaíba, Brasil. 132p.

Chen, C., Zhang, Y., Xu, Z., Luan, A., Mao, Q., Feng, J., He, Y. 2016. Transcriptome profiling of the pineapple under low temperature to facilitate its breeding for cold tolerance. *PLoS One* 11: e0163315.

Cooper, P.I. 1969. The Absorption of Solar Radiation in Solar Stills. *Solar Energy* 12: 3.

Cunha, G.A.P. 1989. Eficiência do ethephon, em mistura com hidróxido de cálcio e uréia, na floração do abacaxi. *Revista Brasileira de Fisiologia Vegetal*, Londrina 1: 51-54.

Embrapa. 2021. Recomendações de calagem e adubação para abacaxi, acerola, banana, citros, mamão, mandioca, manga e maracujá. *Embrapa* 2: 631-81.

Fao. Faostat: production, crops, and livestock products. 2020. Disponível em: http://www.fao.org/faostat/en/#data/QCL <Acesso em: 14 jan. 2022>

Firoozabady, E. Young, T.R. Pineapple plant named Rosé (EF2-114). 2013. Disponível em: https://www.google.com/patents/US20130326768 <Acesso em: 17 jul. 2021>

Friend, D.J.C. 1981. Effect of night temperature on flowering and fruit size in pineapple (*Ananas comosus* (L.) Merr.). *Bot. Gaz*. 142: 188-190.

Gowing, D.P. 1961. Experiments on the photoperiodic response in pineapple. *American Journal of Botany* 48: 16–21.

Ledo, A.D.S., Gondim, T.M.D.S., Oliveira, T.K.D., Negreiros, J.R.D.S., Azevedo, F.F.D. 2004. Efeito de indutores de florescimento nas cultivares de abacaxizeiro RBR-1, SNG-2 e SNG-3 em Rio Branco-Acre. *Revista Brasileira de Fruticultura* 26: 395-398.

Li, Z., Wang, J., Zhang, X., Lei, M., Fu, Y., Zhang, J., Xu, L. 2016. Transcriptome sequencing determined flowering pathway genes in *Aechmea fasciata* treated with ethylene. *Journal of Plant Growth Regulation* 35: 316-329.

Liu, C.H., Fan, C. 2016. De novo transcriptome assembly of floral buds of pineapple and identification of differentially expressed genes in response to ethephon induction. *Frontiers in Plant Science* 7: 203–203.

Liu, S., Zhang, X., Zhang, Y., Li, Y., Zhu, Z. 2020. Forced flowering of pineapple (*Ananas comosus* cv. Tainon 16) in response to ethephon with or without calcium carbonate. *Plant Growth Regulation* 60: 83-90.

Martins, J.A., Dallacort, R., Inoue, M.H., Santi, A., Kolling, E.M., Coletti, A.J. 2010. Probabilidade de precipitação para a microrregião de Tangará da Serra, estado de Mato Grosso. *Pesquisa Agropecuária Tropical* 40: 291-296.

Oliveira, A.M.G., Junghans, D.T., Cunha, G.A.P. 2009. *Sistema de Produção de Abacaxi para o Extremo Sul da Bahia.* Embrapa, Cruz das Almas, Brasil. 63 p.

Pereira, F. D. N., Oliveira, F. D. P., Tebinka, V. Pádua, T. R. P., Matos, A. P. 2015. *Índice de florescimento natural e parâmetros de crescimento de folha" D" de abacaxizeiro pérola em função de peso de mudas e irrigação em sistema orgânico de produção.* Embrapa, Cruz das Almas, Brasil. 5 p.

Queiroz, C.R.P., Lorenzoni, M.M., Ferreira, F.R., Cabral, J.R.S. 2003. *Catálogo de caracterização e avaliação de germoplasma de abacaxi.* Embrapa, Brasília, Brasil. 52 p.

R Core Team R: A Language and Environment for Statical Computing. 2017. Disponível em: http:/Www.R-Project.Org/.2017 <Acesso em: 17 jul. 2021>

Ricce, W.S., Carvalho, S.L.C., Caramori, P.H., Auler, P.A.M., Roberto, S.R. 2014. Agroclimatic zoning for pineapple cultivation in the state of Paraná, Brazil. *Semina: Ciências Agrárias* 35: 2337-2346.

Sanewski, G.M., Bartholomew, D.P. 2018. Inflorescence and Fruit Development and Yield. In: Sanewski, G.M., Bartholomew, D.P., Paull, R.E. *The Pineapple: Botany, Production and Uses*. CABI, Manoa, USA. p.29.

Santos, P.C., Silva, M.P.S., Carvalho, A.J.C., Freitas, M.S.M., Petri, D.J.C., 2018. Pineapple plantlets 'Vitória' fertilized with potassium chloride and silicic acid: growth and nutritional composition. *Revista Brasileira de Ciências Agrárias* 12: 309-315.

Song, Y.H., Ito, S., 2013. Imaizumi, T. Flowering time regulation: photoperiod-and temperature-sensing in leaves. *Trends in plant science* 18: 575-583.

Trusov, Y., Botella, J.R. 2006. Silencing of the ACC synthase gene ACACS2 causes delayed flowering in pineapple [*Ananas comosus* (L.) Merr.]. *Journal of experimental botany* 57: 3953-3960.

Van Doorn, W.G., Kamdee, C. 2014. Flower opening and closure: an update. *Journal of experimental botany* 65: 5749-5757.

Wang, R.H., Hsu, Y.M., Bartholomew, D.P., Maruthasalam, S., Lin, C.H. 2007. Delaying natural flowering in pineapple through foliar application of aviglycine, an inhibitor of ethylene biosynthesis. *HortScience* 42: 1188-1191.

Young, R., Gonzales, J. Pineapple plant named 'DOLE-14'. 2010. Disponível em: https://patentimages.storage.googleapis.com/17/af/d0/33572a493e5be1/USPP20885.pdf <Acesso em: 01 jul. 2022>

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.