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Citrus postbloom fruit drop occurrence in Southern Brazil during El Niño Southern Oscillation (ENSO) phases

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ABSTRACT

Citrus postbloom fruit drop (PFD) disease causes large yield losses in orchards, when flowering coincides with intense and prolonged rainfall. Thus, studies related to models that predict the climate effect on PFD are of the utmost importance as they can improve disease control efficiency mainly when considering climate variability, which is mostly caused in Brazil by El Niño Southern Oscillation (ENSO) phases. The objective of this study was to assess the effect of the ENSO phases on PFD in different regions in Southern Brazil aiming to allow a better disease management. For that, weather data of 67 years (1950 - 2016), of five regions in São Paulo state: Bebedouro, Descalvado, Piracicaba, Itapetininga, Santa Cruz do Rio Pardo, and one in Paraná (Maringá), were employed to estimate PFD incidence, based on a phenological-climatological model. The results indicated that there is no clear consensus about the ENOS influence on PFD incidence in citrus in the assessed regions. El Niño years, in Itapetininga, and El Niño and La Niña years in Descalvado are those with higher PFD incidence. For the other assessed locations, no differences were observed for PFD between ENSO phases. When considering the general PFD incidence, differences were observed only between Bebedouro, with the lowest incidence (32.2%), and Itapetininga and Descalvado, where incidence reached 51.2% and 49.5%, respectively.

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Introduction

Brazil is one of the most important citrus producers in the world, contributing with almost 30% of the global orange (*Citrus sinensis*) production (FAO, 2020). São Paulo State is the most important orange producer, accounting for about 73% of national production, followed by states of Minas Gerais, Bahia and Paraná, which contributes with 5 to 6% each (IBGE, 2020). Due to diseases emerged between 1990 and 2000, mainly Huanglongbing (HLB), and sugarcane expansion in Southern Brazil, there was a reduction of orange orchards in the traditional areas, in the center and north of the state of São Paulo, and a growth of them into the south of this state (Neves, 2010), a more humid region (Alvares et al., 2014), more favorable for diseases, which brought new challenges for this crop.

Because of its perennial behavior, citrus crops are very influenced by climate conditions all year long, with temperature, solar radiation, and rainfall amount and distribution being the most important for them (Reuther, 1977; Sentelhas, 2005). Besides growth, development and yield, the climate also affects the dynamics of citrus plants and pathogens relationships, which negatively impact yields when an infection process is established. Among the main citrus diseases, the most important are HLB (*Candidatus Liberibacter asiaticus*/*Candidatus Liberibacter americanus*), citrus canker (*Xanthomonas citri subsp citri*), citrus variegated chlorosis (*Xylella fastidiosa*), citrus black spot (*Phyllosticta citricarpa*), and postbloom fruit drop (PFD, *Colletotrichum acutatum*, Porto et al. (1993), and *Colletotrichum gloeosporioides*, Lima et al. (2011)). Among these diseases, PFD stands out as of high importance since it affects flowering and, therefore, fruits production.

C. acutatum and *C. gloeosporioides* infect the petals of the citrus flowers and cause early release of small fruits, retaining the peduncle and calyces on the branches (popularly known in Brazil as "estrelinha") (Timmer et al., 1994). The symptoms of fruit drop are therefore characteristic and easy to identify. Orange and acid lime trees are the most susceptible to PFD, while mandarins are less affected by this disease (Feichtenberger, 1991). PFD is conditioned by air temperature and wetness duration during flowering (Timmer et al., 1994; Peres et al., 2004, Gama et al., 2019).

Denham and Waller (1981) observed considerable amounts of PFD when periods of rain were followed by prolonged wetness (about 20 h) during peak blossoming periods. The introduction of this disease in areas where it has not yet been reported is sudden, causing losses close to 100% (Timmer et al., 1994; Peres et al., 2004). The control of PFD is primarily through fungicide sprays, which is not always necessary as PFD occurs sporadically according to climate conditions and inoculum presence in the area (Timmer et al., 1994; Peres et al., 2004; Soares-Colletti et al., 2016; Gama et al., 2019).

Citrus flower abundance varies by cultivar through the initiation and length of the flowering window which is greatly affected by weather conditions. As PFD onset occurs through citrus flowers, it is crucial to know how climate variability impacts citrus flowering and disease development. Understanding this variability to predict pathogen infection during flowering window would facilitate more effective decision-making for disease control (Timmer et al., 1994; Soares-Colletti et al., 2016). Currently, very few is known about the climate variability and PFD occurrence in citrus orchards in Brazil, making the control limited to the calendar schedule, which is sometimes more intensive than required.

Considering the weather dependence of PFD occurrence on citrus orchards, El Niño-Southern Oscillation (ENSO) in its different phases, "neutral" (N), "warm" (El Niño, EN), and "cold" (La Niña, LN), may influence disease intensity, since they affect air temperature and rainfall patterns in different ways around the citrus-producing regions of Southern Brazil, promoting large variation in crop yield, quality, and sanity. Studies about the influence of ENSO phenomenon on plant disease intensity in Brazil have been conducted for wheat Fusarium Head Blight (Del Ponte et al., 2009), Asian soybean rust (Del Ponte et al., 2011), *Eucalyptus* rust (Nóia Júnior et al., 2019), coffee leaf rust (Hinnah et al., 2020), and cocoa moniliasis (Galvão et al., 2020). These studies showed that ENSO phases were useful to explain disease intensity interannual variability, due to the impact of this phenomenon on weather conditions, which also depends on the geographical position in the country. However, as far as we know, studies considering the influence of ENSO phases on citrus diseases do not exist yet. Therefore, studies like that could be useful to improve the strategies of disease control in citrus orchards, mainly for PFD. The first step to investigate the relationship between ENSO phases and PFD incidence is to have an accurate disease occurrence model based on weather data, such as the one developed by Soares-Colletti et al. (2016), which integrates a phenological model for estimating flowering date and duration, based on growing degree-days, with a climatological disease model, based on accumulated rainfall during the interval between peak of flowering and 50% of remaining flowers. Therefore, this study aimed to estimate PFD incidence with the phenological-climatological model developed by Soares-Colletti et al. (2016), which requires air temperature and rainfall data, for the main citrus-producing regions in Southern Brazil (Bebedouro, Descalvado, Piracicaba, Itapetininga, Santa Cruz do Rio Pardo, in the state of São Paulo, and Maringá, in the state of Paraná) for a period of 67 years, and based on that to assess the ENSO phases effects on disease intensity according to the effect that this phenomenon has on weather conditions. The outcomes of this research will allow to provide information for improved disease control in the assessed region.

Material and Methods

Study areas and climate data

The study was carried out for six different citrus-producing regions in Southern Brazil where orange production in already well-established, according to the National Agricultural Survey (IBGE, 2020). These regions are concentrated mainly in the states of São Paulo and Paraná and are represented by the following sites: Bebedouro; Descalvado; Piracicaba; Itapetininga; and Santa Cruz do Rio Pardo, in the state of São Paulo, and Maringá

Figure 1. Spatial distribution of the locations considered in the present study in the states of São Paulo (Bebedouro, Descalvado, Itapetininga, Piracicaba and Santa Cruz do Rio Pardo) and Paraná (Maringá), Brazil.

Table 1. Citrus-producing regions in Southern Brazil and the sources of weather data used in the present study to have a continuous period from 1950 to 2016.

Location, State	Coordinates	Sources of data
Bebedouro, SP	20.89° S, 48.47° W	EEB[1]; ANA[2]; IAC[3]
Descalvado, SP	21.37° S, 47,37° W	CIIAGRO; ANA
Piracicaba, SP	22.71° S, 47.42° W	ESALQ[4]
Itapetininga, SP	23.52° S, 48.06° W	IAC; ANA
Santa Cruz do Rio Pardo, SP	22.53° S, 49,37° W	IAC; ANA
Maringá, PR	23.40° S, 51.91° W	INMET[5]; ANA

[1] Bebedouro Citrus Experimental Station; [2] National Water Agency; [3] Agronomic Institute of Campinas; [4] "Luiz de Queiroz" College of Agriculture, University of São Paulo; [5] National Institute of Meteorology.

in the state of Paraná (Fig. 1 and Table 1). These sites represent an area of orange production of approximately 400,000 ha, about 45% of the total area in the country (IBGE 2020). Daily weather data (maximum and minimum air temperature and rainfall) from 1950 to 2016 were obtained from different sources, as presented in Table 1, in order to have a continuous historical data series. These data were firstly used for making a general agroclimatic characterization of each studied region, through the climatological water balance for a soil water holding capacity (SWHC) of 100 mm (Thornthwaite & Mather, 1955), which has as input average monthly rainfall and potential evapotranspiration, estimated by the method proposed by Thornthwaite (1948), which has a reasonable performance for the studied region in a monthly time-scale (Camargo & Sentelhas, 1997). The SWHC of 100 mm is a common value used to represent the average conditions for the citrus-producing regions, as considered by Soares-Colletti et al. (2016). Secondly, the daily weather data were employed for estimating annual PFD incidence for the historical series, as will be described below.

PFD phenological-climatological model

PFD incidence was estimated by the phenological-climatological model developed by Soares-Colletti et al. (2016). This model was chosen because it uses daily average temperature (Tavg, calculated as the average of daily maximum and minimum air temperatures from the data series) and rainfall, which are available for most of the long-term data series in Brazil and also because it was well-validated for the region under evaluation, with a R^2 = 0.79 and Mean Absolute Percentage Error (MAPE) of 10.9%. Simulations with this model were carried out for 67 years (1950 to 2016). A description of Soares-Colletti et al. (2016) model is presented below, and further details can be found in the original paper. The model has two submodels: citrus flowering phenology and PFD estimation.

The flowering phenology submodel was based on growing degree-days, considering a base temperature of 13°C. According to the model, the flowering process begins when the minimum temperature (Tmin) reaches less than 10 °C during June and July in the growing regions of Southern Brazil, followed by a cumulative rainfall of at least 20 mm within 5 days. Once these conditions occur, after 96 °C day the citrus trees will bloom. After that, the duration of the flowering period and subperiods will be controlled by thermal time (degree days): 147 °C day for bloom beginning to peak of flowering; 206 °C day from the peak of flowering to 50% of the remaining flowers; 13 °C day from 50% of remaining flowers to end of petals fall. For the locations upper north, like Bebedouro, where Tmin < 10 °C does not occur in some years, the intense water deficit that is normally observed in this region during the winter is enough to stimulate the flowering process (Ribeiro et al., 2006). Under this condition, bloom starts when a total rainfall of at least 20 mm within 5 days occurs after the dry season.

The disease submodel estimates PFD incidence as a function of accumulated rainfall during the most susceptible flowering period. This approach assumes that *C. acutatum* and *C. gloeosporioides* are always present in the area and in an enough amount to start an outbreak. This assumption is close to the actual conditions in the citrus areas of the states of São Paulo and Paraná, where weather during the winter is not severe enough to reduce the population of pathogens (Bergamin Filho & Amorim, 1996). Another assumption of our study is that no PFD control was performed, which means that only climate conditions were considered for disease occurrence, once there is no resistant citrus variety for this disease. The submodel used for estimating PFD incidence is based on a Gompertz equation, adjusted by Soares-Colletti et al. (2016), for the relationship between PFD incidence and total rainfall from flowering peak to 50% of the remaining flowers (called hereafter as "critical period"), according to the equation below:

$$I_{PFD} = e^{\left[-7.083 \times e^{-0.033 \times R}\right]} \quad \text{(Eq.1)}$$

where: I_{PFD} is the estimated PFD incidence and R is the accumulated rainfall (mm) during the critical period.

ENSO influence

To assess the influence of ENSO phases, from 1950 to 2016, on PFD incidence, the different events of this oceanic-atmospheric phenomenon were classified based on sea surface temperature anomalies (SSTA) of the 3.4 Niño region in Equatorial Pacific Ocean, obtained from the National Oceanic and Atmospheric Administration (www.noaa.gov): Neutral - N (-0.5 ºC < SSTA < +0.5 ºC); Warm or El Niño – EN (SSTA ≥ +0.5°C); and Cold or La Niña – LN (SSTA ≤ -0.5 ºC). The ENSO phases were classified considering the months prior to the citrus flowering induction period, being considered a three-month running average from December/January/February to June/July/August. The ENOS phase that predominated during these seven three-month periods was assumed as the one considered for the analysis.

Statistical and simulations analysis

The statistical analysis of average PFD incidence among the assessed regions and ENSO phases were performed by analysis of variance and by the Tukey's test at 5% of significance. The software SISVAR was used for this purpose (Ferreira, 2011). The estimated PFD incidence data were transformed by a quadratic model in order to achieve a linear relationship. The results of the simulations were analyzed through boxplot and violin plots, using the *ggplot2* package (Wickham, 2016) in the *R* environment (R CORE TEAM, 2018).

Results and Discussion

Agro-climatic characterization

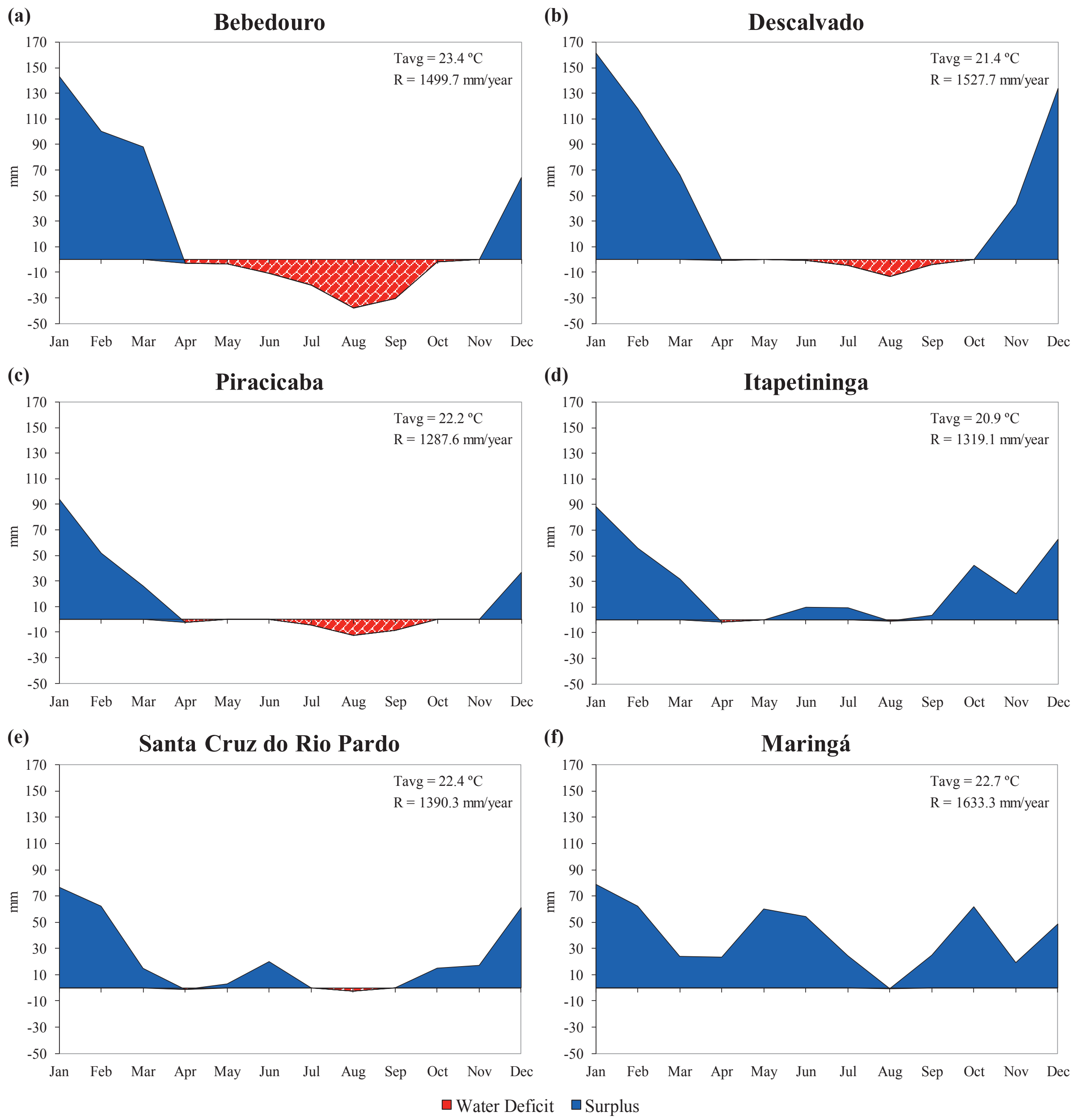
The water balances of the sites assessed, as well as their long-term annual average of accumulated rainfall and Tavg are presented in Fig. 2. Bebedouro, Descalvado and Piracicaba presented the highest water deficits during the year, which were concentrated mainly from June to mid-September, except for Bebedouro where the dry season started earlier, in April. Itapetininga and Santa Cruz do Rio Pardo had similar water balances, with no water deficit along the year; however, Itapetininga had a lower annual Tavg (20.9 °C), which also led to lower potential evapotranspiration. In Bebedouro and Descalvado, the amount of summer rainfall was higher than observed in the other locations, resulting in more water surplus. Finally, in Maringá, the rainfall was well distributed along the year, which associated with the mild temperatures resulted in the occurrence of water surplus all year long.

The average annual rainfall in the assessed sites ranged from 1288 mm in Piracicaba to 1633 mm in Maringá, while the annual Tavg varied between 20.9 °C in Itapetininga and 23.4 °C in Bebedouro. In all assessed sites, the rainy season started between the end of September and November and lasts till April, which were basically conditioned by the influence of South Atlantic convergence zone (SACZ) associated with frontal systems (Cavalcanti et al., 2009). As the main citrus flowering period in Southern Brazil occurs between September and November, PFD will vary according to rainfall amount and distribution during these months.

PFD frequency and conditioning factors

From Fig. 3a it is possible to identify all the seasonal and interannual variability for Tavg, with Bebedouro and Itapetininga showing the highest and the lowest values during the critical period, respectively. The other sites had similar thermal regimes, with differences no greater than 2 °C. As the duration of the critical period is directly affected by Tvg, these variabilities influenced the number of days between bloom peak and 50% of remaining flowers, with

Figure 2. Long term climatological water balance and annual average air temperature (Tavg) and rainfall (R), for the period between 1950 and 2016, for Bebedouro (a), Descalvado (b), Piracicaba (c), Itapetininga (d), Santa Cruz do Rio Pardo (e), in the state of São Paulo, and Maringá (f), in the state of Paraná, Brazil.

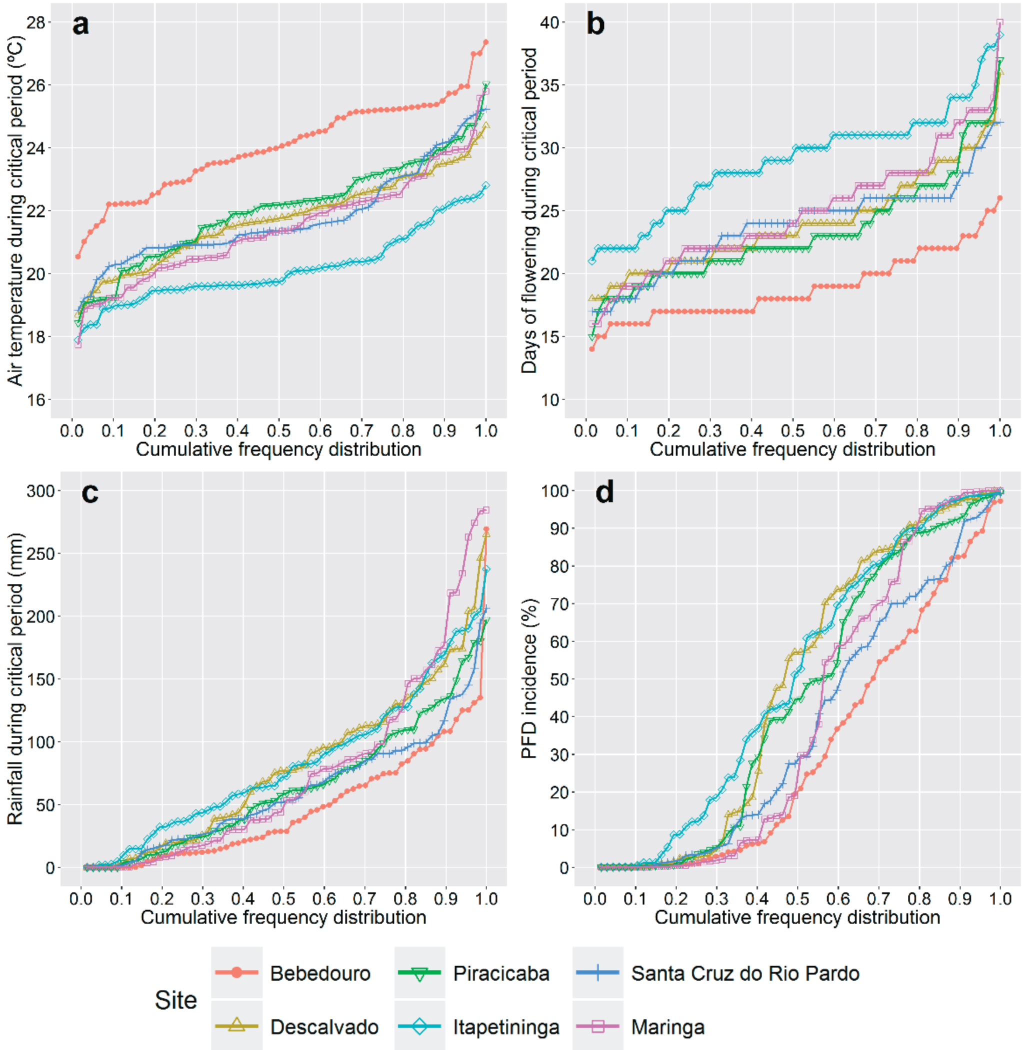


Bebedouro presenting, in average, the shortest one, with 19 days (ranging between 14 and 26 days), and Itapetininga the longest, with an average of 29 days (ranging between 21 and 39 days) (Fig. 3b). For the other locations, the average critical period was very close, ranging between 23 and 24 days, but with considerable interannual variability, between 15 and 41 days (Fig. 3b).

The rainfall during the critical period showed an expressive interannual variability, ranging from 0 to 285 mm (Fig. 3c). In 70% of the years, Itapetininga and Descalvado presented a total rainfall in the mentioned period below 105 mm; in contrast, for Maringá, Piracicaba and Santa Cruz do Rio Pardo it was below 90 mm, and in Bebedouro below 75 mm. In Maringá, in 10% of the years the rainfall in the critical periods was higher than 218 mm, revealing very favorable conditions for PFD occurrence.

Total rainfall during the critical period resulted in PFD incidences presented in Fig. 3d, which reveals very distinct conditions for the assessed citrus regions in Southern Brazil. The average PFD incidence ranged between 32% in Bebedouro and 51% in Itapetininga. Such difference , of about 20%, is expressive since it is directly related to the number of fruits produced and, therefore, to yield. Taking 20% of PFD incidence as a suitable maximum limit for citrus orchards, Itapetininga showed to be the region with the highest risk for this disease, since 70% of the years are

Figure 3. Cumulative frequency distribution of average air temperature (a), number of rainy days (b) and total rainfall (c) during the critical period of citrus flowering (bloom peak till 50% of remaining flowers), and the citrus PFD incidence (d) for diferent producing regions in Southern Brazil: Bebedouro; Descalvado; Itapetininga; Piracicaba; and Santa Cruz do Rio Pardo, in the state of São Paulo; and Maringá, in the state of Paraná.



above such limit, followed by Piracicaba (63%), Descalvado (61%), Santa Cruz do Rio Pardo (55%), and Bebedouro and Maringá (50%) (Fig. 3d).

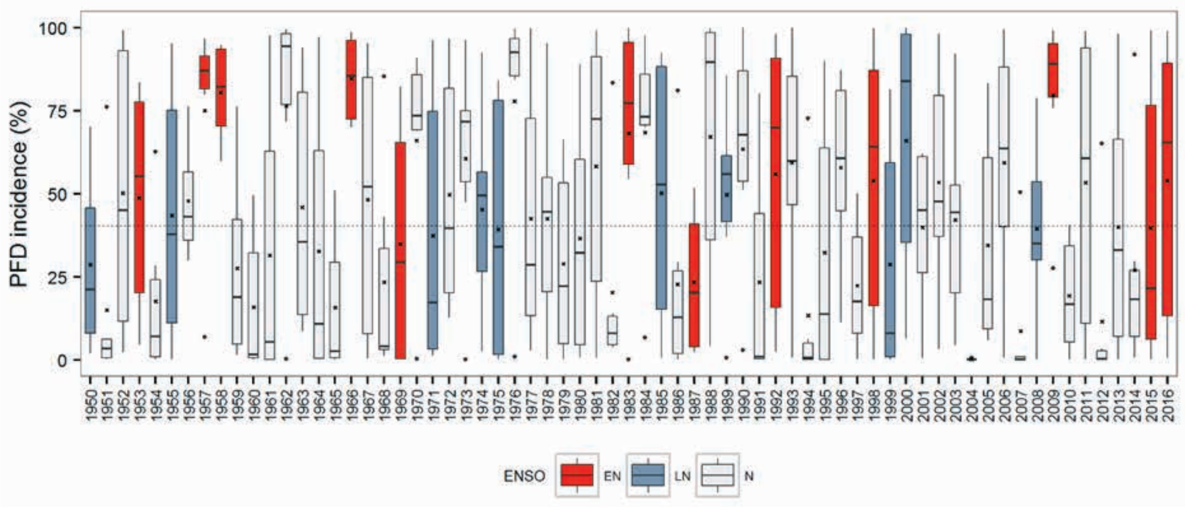
Inter and intra-annual PFD incidence variability under different ENSO phases

Inter and intra-annual PFD incidence variability, considering the different phases of ENSO, are presented in Fig. 4. The overall median of PFD incidence was 40.5%. The results show that there is an appreciable variability of PFD incidence among years, sites and ENSO phases, as a consequence of the complexity of this pathosystem, which involves a synchronism between citrus tree phenology and climatic conditions. In a general analysis, during EN years a tendency of higher disease incidence was observed in Southern Brazil, with 9 out of 12 years (75%) presenting PFD incidence above the overall median. For the other ENSO phases (LN and N), no tendency was clearly observed (Fig. 4).

Regarding the spatial variability of PFD incidence, a huge variability was observed (Fig. 4), with some years showing variability from zero to 100%, like in 1993 (N), 1998 (EN), and 2015 (EN), and others having very little variation among producing regions, as observed in 1951 (N), 1957 (EN), 1976 (N), 1982 (N), 1994 (N), 2004 (N), 2007 (N), 2009 (EN), 2012 (N). All these years were under the influence of EN or N phases of ENSO, when climate conditions were very similar in all assessed regions leading to very high or very low PFD incidence.

Considering the entire historical series, five EN years (1957, 1958, 1966, 1983 and 2009) out of 12, and six N years (1962, 1970, 1973, 1976, 1984 and 1990) out of 10 had all regions with their PFD incidence above of the overall median (Fig. 4), which never happened during LN years.

Figure 4. Inter and intrannual variability of citrus postbloom fruit drop (PFD) incidence for all assessed producing regions in Southern Brazil: Bebedouro; Descalvado; Itapetininga; Piracicaba; and Santa Cruz do Rio Pardo, in the state of São Paulo; and Maringá, in the state of Paraná, for the period between 1950 and 2016, considering the different phases of the El Niño Southern Oscillation (ENSO): El Niño (EN); La Niña (LN); and Neutral (N). In the boxplot, the full central line is median, the dot inside the bar is the percentile 50%, the upper and lower limits of the bars are the percentiles 25% and 75%, vertical lines are the percentiles 10% and 90%, and black points refer to the outliers. Each boxplot represents all locations assessed on the same season. The overall mean PDF incidence (40.5%) is represented by the dotted straight line.



On the other hand, only during ten N years (1951, 1954, 1982, 1986, 1994, 2004, 2007, 2010, 2012 and 2014) out of 45, all regions presented PFD incidence below the overall median (Fig. 4).

All sites presented high PFD incidence variability, but with the median being higher during EN years, except for Bebedouro, where the PFD incidence was a little bit higher during N years. Despite the PFD incidence be higher in EN years in Descalvado, the estimated disease during LN years also presented a high level of occurrence, with the median being higher than N years (Fig. 5).

Average PFD incidence for the assessed locations and for each ENSO phase are presented in Table 2. According to this analysis, Itapetininga and Descalvado are the locations with the highest general PFD incidence; however, they did not differ ($p < 0.05$) from Piracicaba, Santa Cruz do Rio Pardo, and Maringá, which were also similar to what was observed in Bebedouro. The differences of PFD incidence were only expressive between Bebedouro, with a disease incidence of 32.2%, and Itapetininga and Descalvado, with PFD incidence above 49% ($p < 0.05$). In relation to ENSO phases, no difference ($p < 0.05$) was observed for PFD incidence among them for Bebedouro, Piracicaba, Santa Cruz do Rio Pardo, and Maringá. For Descalvado, during EN years the citrus PFD incidence showed to be higher (≈ 74%) than the values observed during N years (≈ 41%), whereas the disease incidence during LN years did not differ from those during the other ENSO phases ($p < 0.05$). Similar results were obtained for Itapetininga, where the incidence of PFD was higher during EN years (≈ 80%) than during the other ENSO phases.

Discussion

In the state of São Paulo, historical observations showed that PFD caused significant citrus yield losses during the years 1977, 1978, 1990, 1991, 1993, 1996, 1998 and 2009 (Rossetti et al., 1981 cited by Soares-Colletti et al., 2016; Feichtenberger, 1991; Porto, 1993; Peres et al., 2004; FUNDECITRUS, 2018). Among all these years, only 1998 and 2009 were EN years, while all others were neutral. Except for 1990 and 2009, all the other years presented a huge PFD incidence variability among the assessed regions; however, all of them reached very high incidences (> 70%) in at least one of the regions. In 2009, the citrus PFD incidence was very high in all sites, between 80 and 100%, showing that the weather conditions were very similar during the critical period of the citrus flowering in all evaluated regions. Another critical aspect in this context is that all regions are traditional citrus producers and already presented high inoculum amount, a crucial factor for disease occurrence (Timmer and Zitko, 1993; Peres, 2002).

Even though the phenological-climatological model of Soares-Colletti et al. (2016) does not take into account other factors that affect citrus PFD epidemics, such as host resistance, crop management, and inoculum amount, this study allowed to assess the climate variability that was consistent with the observed PFD variation in the studied sites. The regions of Itapetininga and Descalvado are those with the highest favorability for PFD occurrence, followed by Piracicaba, Santa Cruz do Rio Pardo and Maringá, which did not differ among them. On the other hand, in Bebedouro, where the climatic conditions during the flowering critical period are less favorable for PFD, the disease incidence was

Figure 5. Interannual variability (box-plots) and frequency of distribution (colored areas) of citrus postbloom fruit drop (PFD) incidences during El Niño (EN), La Niña (LN) and neutral (N) phases of El Niño/Southern Oscillation (ENSO) phenomenon in Bebedouro, Descalvado, Piracicaba, Itapetininga, Santa Cruz do Rio Pardo in the state of São Paulo, and Maringá, in the state of Paraná. In the boxplot, the full central line is median, the dot inside the bar is the percentile 50%, the upper and lower limits of the bars are the percentiles 25% and 75%, vertical lines are the percentiles 10% and 90%, and black points refer to the outliers. Each boxplot represents all years of each ENSO phase. The shaded areas (red, dark blue and gray) represent the frequency of PFD incidence.

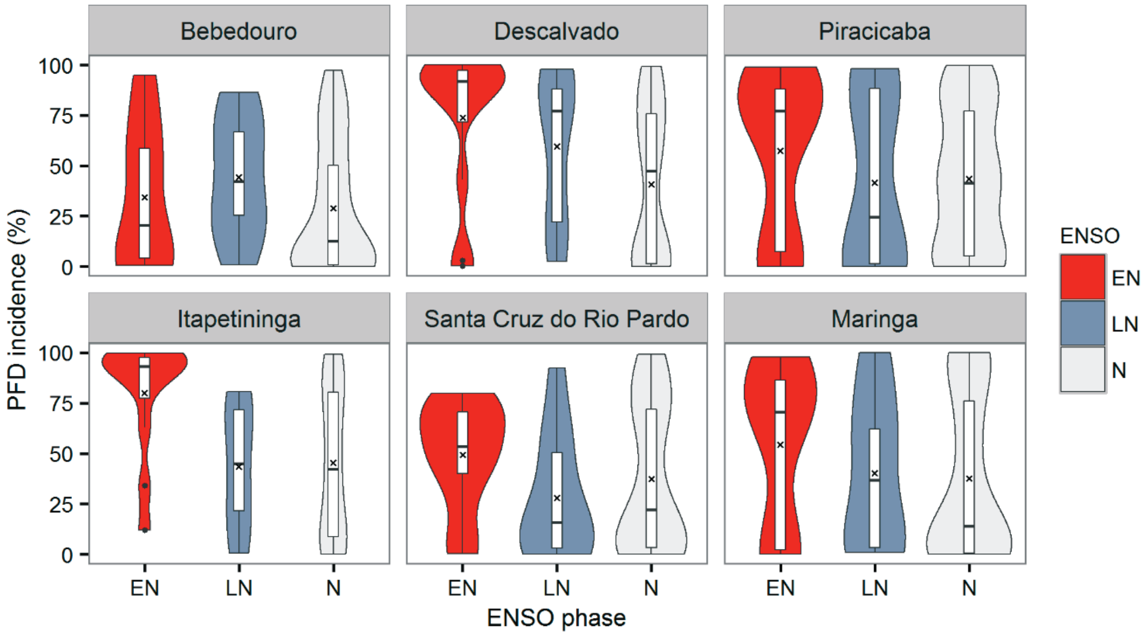


Table 2. Analysis of variance of Postbloom fruit drop (PFD) incidence in all citrus-producing regions in Southern Brazil during different El Niño Southern Oscillation (ENSO) phases: El Niño (EN); La Niña (LN); and Neutral (N).

ENSO phase	Bebedouro	Descalvado	Piracicaba	Itapetininga	S. C. R. Pardo	Maringá
EN	34.35 a*	73.87 b	57.36 a	79.92 b	49.31 a	54.32 a
N	28.94 a	40.71 a	43.54 a	45.29 a	37.31 a	37.64 a
LN	44.27 a	59.49 ab	41.61 a	43.38 a	28.00 a	40.23 a
LSD**			31.66***			
Average	32.20 A*	49.45 B	45.73 AB	51.21 B	38.07 AB	41.01 AB
LSD**			17.98***			

*Means followed by the same lowercase letter in the column or line (for ENSO phases and locations) or followed by the same uppercase letter in the line (for locations average) do not differ by Tukey test at 5% probability; ** least significant difference; *** Significant at 0.05 probability level.

lower, which differed from Itapetininga, but not from the other locations.

Even considering that EN years were those that presented, in general, the highest PFD incidence, differences in relation to the other ENSO phases were only observed for Itapetininga. For Descalvado, PFD incidence was higher during EN than N years; however, no difference was observed between the PFD incidence during LN years in relation to the other ENSO phases. In Bebedouro, Piracicaba, Santa Cruz do Rio Pardo, and Maringá, PFD incidence did not differ for any of the ENSO phases. The possible hypothesis to explain such low influence of ENSO phases on PFD is that other atmospheric phenomena can also be interfering on the weather conditions and that this disease occurs when citrus plants are flowering, which normally happen between August and October, period when the intensity of ENSO phases is still weak and not well-defined.

The present results are similar to what was obtained by Nóia Júnior et al. (2019) for *Eucalyptus* rust in Southern Brazil. In that study, the authors found that ENSO phases affected the favorability for *Eucalyptus* rust occurrence in a different way, with the disease severity increasing for the states of Santa Catarina and Paraná during EN, when more rainfall was observed, and reducing in LN years, due to less occurrence of rainfall events. At the other states, including São Paulo, no differences were observed for disease severity among ENSO phases. Del Ponte et al. (2009)

also observed increased spring rainfall linked to warm sea surface temperature in the Pacific (EN) after the 1980s in the state of Rio Grande do Sul, Brazil, which was associated with higher intensity of Fusarium head blight (FHB) epidemics, similar to what was observed by Del Ponte et al. (2011) in the same Brazilian state for Asian soybean rust.

Another study, conducted by Galvão et al. (2020), showed that cocoa moniliasis disease in the state of Bahia, Brazil, located about 1000 km upper north in relation to the region assessed in the present study, has its occurrence favored by neutral ENSO phase, which allows growers to plan disease control in advance, by assessing a seasonal disease forecast, as also highlighted by Del Ponte et al. (2009, 2011). Finally, Hinnah et al. (2020), studying coffee leaf rust in Center-Southern Brazil, found varied responses of the disease to ENSO phases. Whereas in the state of Paraná and south of São Paulo predominate a well-defined influence of ENSO phases on the cumulative infection rate, in upper north coffee areas, like in the states of São Paulo, Minas Gerais, Espírito Santo, Goiás and Bahia, a lack of ENSO influence was found, similar to what was observed for PFD.

In addition to ENSO, other meteorological phenomena such as the Pacific Decadal Oscillation and the South Atlantic Convergence Zone may also interfere in the climate variability of Center-Southern Brazil (Cavalcanti et al., 2009), thus influencing on the intensity of PFD epidemics, as well as other citrus diseases that are rainfall-dependent. As PFD is highly influenced by weather conditions and its control is basically done by chemicals (Feichtenberger et al., 2005; FUNDECITRUS, 2018; Gama et al., 2019), using intervals between applications of 7 to 10 days for warmer and 10 to 14 days for colder periods (Silva Junior, 2011), the knowledge of seasonal forecast could improve the strategies of disease control where ENSO phases showed to affect it, which could be used with other strategies, such as biological control (Kupper et al., 2012; Klein et al., 2016), in order to rationalize the use of fungicides for PFD management. The method presented by Soares-Colletti et al. (2016) to determine PFD incidence can also be used for managing sprays recommendation in a decision support system, since it allows to determine if the control is necessary or not and when it should be applied, similar to what was done by Gama et al. (2019).

Conclusions

There is no clear consensus about the ENOS influence on PFD incidence in citrus orchards in the assessed regions in Southern Brazil, when using the phenological-climatological disease model. El Niño events showed to be more suitable for PFD occurrence only in Itapetininga and Desclavado, whereas for La Niña years just Descalvado presented higher levels of PFD occurrence. On the other hand, for the other studied locations, no differences were observed for PFD incidence between ENSO phases. When considering all years under analysis, only Bebedouro, the site located further north, differed from the others, presenting the lowest incidence (32.2%), whereas Itapetininga and Descalvado were those where PFD incidence showed the highest values, respectively, 51.2% and 49.5%, but not differing from Piracicaba (45.7%), Santa Cruz do Rio Pardo (38.1%), and Maringá (41.0%). The possible hypothesis to explain such low influence of ENSO phases on PFD is that other atmospheric phenomena can also be interfering on the weather conditions and that this disease occurs when citrus plants are flowering, which normally happen between August and October, period when the intensity of ENSO phases is still weak and not well-defined.

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Authors contribution

H. B. DIAS conceptualization, data acquisition, data analysis, writing and editing; A. R. SOARES-COLLETTI design of methodology, writing and editing; F. D. HINNAH data analysis, writing and editing; and P. C. SENTELHAS conceptualization, data analysis, design of methodology, writing and editing.

References

ALVARES, C.A.; MATTOS, E.M.; SENTELHAS, P.C.; MIRANDA, A.C.; STAPE, J.L. Modeling temporal and spatial of leaf wetness duration in Brazil. **Theoretical and Applied Climatology**, v. 120, p. 455-467, 2015.

BERGAMIN FILHO, A.; AMORIM, L. **Doenças de plantas tropicais: epidemiologia e controle econômico**. São Paulo, SP: Editora Agronomica Ceres, 1996. 289 p.

CAVALCANTI, I.F.A.; FERREIRA, N.J.; SILVA, M.G.A.J.; DIAS, M.A.F.S. **Tempo e Clima no Brasil**. São Paulo, SP: Oficina de Textos, 2009. 464 p.

DEL PONTE, E.M.; MAIA, A.H.N.; SANTOS, T.V.; MARTINS, E.J.; BAETHGEN, W.E. Early-season warning of soybean rust regional epidemics using El Niño Southern/Oscillation information. **International Journal of Biometeorology**, v. 55, p. 575–583, 2011.

DEL PONTE, E.M.; FERNANDES, J.M.C.; PAVAN, W.; BAETHGEN, W.E. A model-based assessment of the impacts of climate variability on Fusarium Head Blight seasonal risk in Southern Brazil. **Journal of Phytopathology**, v. 157, p.675–681, 2009.

DENHAM, T.G.; WALLER, J.W. Some epidemiological aspects of postbloom fruit drop disease (*Colletotrichum gloeosporioides*) in citrus. **Annals of Applied Biology**, v. 98, p. 65–67, 1981.

FAO (2020) FAO. http://www.fao.org/faostat/en/#home. Accessed 14 Jun 2020

FEICHTENBERGER, E. Queda de frutos jovens e citros, doença induzida por uma raça virulenta do fungo *Colletotrichum gloeosporioides*. **Laranja**, v. 12, p. 513–521, 1991.

FEICHTENBERGER, E.; BASSANEZI, R.B.; SPÓSITO, M.B.; BELLASQUE JÚNIOR, J. Doenças dos citros (*Citrus spp.*). In: KIMATI, H.; AMORIM, L.; REZENDE, J.A.M. (eds) **Manual de Fitopatologia: doenças de plantas cultivadas**. São Paulo, SP: Agronômica Ceres, 2005. p 239–269.

FERREIRA, D.F. Sisvar: a computer statistical analysis system. **Ciência e Agrotecnologia**, v. 35, p. 1039–1042, 2011.

FUNDECITRUS - Doenças e pragas: Podridão floral. http://www.fundecitrus.com.br/doencas/podridao-floral/13. Accessed 12 Jan 2018

GALVÃO, I.M.; PEREIRA, G.S.; SENTELHAS, P.C. Climatic risk zoning for potential occurrence of cocoa moniliasis in Northeastern Brazil. **Theoretical and Applied Climatology**, 2020 (in press).

GAMA, A.B.; SILVA JÚNIOR, G.J.; PERES, N.A.; MOLINA, J.E.; LIMA, L.M.; AMORIM, L. A threshold-based decision-support system for fungicide application provides cost effective control of citrus postbloom fruit drop. **Plant Disease**, v. 103, p. 2433-2442, 2019.

HINNAH, F.D.; SENTELHAS, P.C.; GLEASON, M.L.; DIXON, P.M.; ZHANK, X. Assessing the biogeography of coffee rust risk in Brazil as affected by El Niño Southern Oscillation. **Plant Disease**, v. 104, p. 1013-1018, 2020.

IBGE - Sistema de recuperação automática (SIDRA). In: Inst. Bras. Geogr. e Estatística. http://www.sidra.ibge.gov.br/. Accessed 14 Jun 2020

KLEIN, M.; SILVA, A.C.; KUPPER K.A. Bacillus subtilis based-formulation for the control of postbloom fruit drop of citrus. **World Journal of Microbiology Biotechnology**, v. 32, p. 1–11, 2016.

KUPPER, K.C.; CORRÊA, F.E.; AZEVEDO, F.A.; SILVA, A.C. *Bacillus subtilis* to biological control of postbloom fruit drop caused by *Colletotrichum acutatum* under field conditions. **Scientia Horticulturae**, v. 134, p. 139–143, 2012.

LIMA, W.G.; SPÓSITO, M.B.; AMORIM, L.; GONÇALVES, M.P. *Colletotrichum gloeosporioides*, a new causal agent of citrus post-bloom fruit drop. **European Journal of Plant Pathology**, v. 131, p. 157–165, 2011.

NEVES, M.F. **O retrato da citricultura brasileira**. Ribeirão Preto, SP: CitrusBR, 2010. 71p.

NÓIA JÚNIOR, R.S.; SCHWERZ, F.; SAFANELLI, J.L.; RODRIGUES, J.C.; SENTELHAS, P.C. Eucalyptus rust climatic risk as affected by topography and ENSO phenomenon. **Australasian Plant Pathology**, v. 48, p. 131–141, 2019

PERES, N.A.R. **Modelo de previsão e controle da podridão floral dos citros causada por *Colletotrichum acutatum***. 2002. 115 p. Tese (Doutorado em Agronomia) - Universidade Estadual Paulista "Júlio de Mesquita Filho", Botucatu.

PERES, N.A.R.; SOUZA, N.L.; FURTADO, E.L.; TIMMER, L.W. Evaluation of systems for timing of fungicide sprays for control of postbloom drop of citrus in Brazil. **Plant Disease**, v. 88, p. 731–735, 2004

PORTO, O.M. Queda anormal de frutos jovens de citros. **Laranja**, v. 14, p. 341–356, 1993.

R CORE TEAM. R: A language and environment for statistical computing. R Foundation for Statistical Computing. 2018. http://www.r-project.org/.

REUTHER, W. Citrus. In: ALVIM, P.T.; KOZLOWSKI, T.T. (ed) **Ecophysiology of tropical crops**. New York: Academic Press, 1977. p. 409–439

RIBEIRO, R.V.; MACHADO, E.C.; BRUNINI, O. Ocorrência de condições ambientais para a indução do florescimento de laranjeiras no Estado de São Paulo. **Revista Brasileira de Fruticultura**, v. 28, p. 247–253, 2006.

SENTELHAS, P.C. Agrometeorologia dos citros. In: MATTOS JÚNIOR, D.; NEGRI, J.D.; PIO, R.M.; POMPEU JÚNIOR, J. (eds) **Citros**. Campinas: IAC/Fundag, 2005. p. 317–344.

SILVA JÚNIOR, G.J. **Podridão floral dos citros: dinâmicas temporal e espacial, sensibilidade de *Colletotrichum acutatum* a fungicidas e controle da doença**. 2011. 131 p. Tese (Doutorado em Ciências) - Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo - Piracicaba.

SOARES-COLLETTI, A.R.; ALVARES, C.A.; SENTELHAS, P.C. An agro-climatic approach to determine citrus postbloom fruit drop risk in Southern Brazil. **International Journal of Biometeorology**, v. 60, p. 891–905, 2016

THORNTHWAITE, C.W.; MATHER, J.R. **The Water Balance**. Centerton: Drexel Institute of Technology - Laboratory of Climatology, 1955. 104p.

TIMMER, L.W.; AGOSTINI, J.P.; ZITKO, S.E.; ZULFIQAR, M. Postbloom fruit drop, an increasingly prevalent disease of citrus in Americas. **Plant Disease**, v. 78, p. 329–334, 1994.

TIMMER, L.W.; ZITKO, S.E. Relationships of environmental factors and inoculum levels to the incidence of postbloom fruit drop of citrus. **Plant Disease**, v. 77, p. 501–504, 1993.

WICKHAM, H. **ggplot2: Elegant Graphics for Data Analysis**. New York: Springer-Verlag, 2016. 260 p.

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Ocorrência da podridão floral dos citros na região Centro-Sul do Brasil nas diferentes fases do El Niño Oscilação Sul (ENOS)

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RESUMO

A podridão floral (PFC) é uma doença que causa sérias perdas nos citros, quando o florescimento coincide com períodos prolongados de chuva. Assim, estudos que estabeleçam o risco climático para a ocorrência da PFC contribuem para o aumento da eficiência do controle, principalmente quando se considera a variabilidade climática, a qual é afetada pelas fases do El Niño Oscilação Sul (ENOS). O objetivo deste estudo foi avaliar os efeitos do ENOS na incidência da PFC em regiões produtoras do Centro-Sul do Brasil, visando dar subsídios para um melhor manejo dessa doença. Para tanto, dados meteorológicos de 67 anos (1950 - 2016), de seis regiões no Centro-Sul do Brasil: Bebedouro, Descalvado, Piracicaba, Itapetininga, Santa Cruz do Rio Pardo, em São Paulo, e Maringá, no Paraná, foram empregados na estimação da incidência da PFC com um modelo fenológico-climatológico. Os resultados indicaram que não há um consenso da influência do ENOS na incidência da PFC nas regiões avaliadas. Os maiores riscos para a doença ocorreram nos anos de El Niño em Itapetininga e de El Niño e La Niña em Descalvado. Para as demais localidades não foram observadas diferenças na PFC entre as fases do ENOS. Quando considerada a incidência geral observou-se diferenças apenas entre Bebedouro, com a menor incidência (32,2%) e Itapetininga e Descalvado, com as maiores, respectivamente, 51,2% e 49,5%.

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REFERENCIAÇÃO

DIAS, H. B.; SOARES-COLLETTI, A. R.; HINNAH, F. D.; SENTELHAS, P.C. Citrus postbloom fruit drop occurrence in Southern Brazil during El Niño Southern Oscillation (ENSO) phases. **Agrometeoros**, Passo Fundo, v.28, e026750, 2020.