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REVIEW

# Advances in the production of temperate fruits in the tropics

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**ABSTRACT.** The present study aimed to review the advances in the production of temperate fruits to determine future research directions that improve production in the tropics. Temperate fruits are no longer only produced in regions characterized by a cold winter period. These fruits are also produced in the sub-tropical and tropical regions characterized by mild winter or even the absence of chilling conditions often required by the tree to break dormancy. Currently, temperate fruit production is possible in certain regions of South America, Africa and Asia that are near to the Equator. However, temperate tree fruit production in tropical regions requires modified techniques to overcome dormancy and allow adequate flowering, growth and productivity. The main approaches taken are the development of cultivars with low chilling requirement, chemical induction of budbreak, interruption of irrigation during the winter period, defoliation, orchard densification, and double pruning. Breeding has become a key tool in the advancement of temperate fruit growing in the tropics, especially with the development of low chilling requirement cultivars.

**Keywords:** chilling requirement; dormancy; climate conditions; tropical; subtropical.

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## Introduction

Temperate tree fruit species originate from locations that have cold winters and well-defined climatic seasons and that have temperatures appropriate to growth during the spring and summer. The domestication of most temperate fruit trees started thousands of years ago in Europe and Asia. Outstanding advances in the development of germplasm and varieties in recent centuries have made these fruit species highly productive (Hauagge, 2000) and made them a critical part of the global tree fruit industry. More recently, the cultivation of fruit trees has been extended to non-traditional areas in the subtropical and tropical regions worldwide, where the climate is different from their natural habitat, with mild and dry winters and hot and rainy summers (Barbosa, Chagas, Pommer, & Pio, 2010).

Temperate fruit trees are characterized by leaf abscission at the end of the growing season in response to a decrease in temperature and photoperiod (Arora, Rowland, & Tanino, 2003), followed by a period of dormancy. Dormancy is defined as the inability to initiate growth from meristems or other organs and cells under favorable growth conditions (Rohde & Bhalerao, 2007). There are three accepted stages of dormancy, namely, endodormancy, ecodormancy and paradormancy (Lang, Early, Martin, & Darnell, 1987). Endo and ecodormancy are the two most relevant types of dormancy for this review. Endodormancy occurs when budbreak and regrowth is restricted because of physiological factors within the dormant bud itself. Ecodormancy occurs when environmental conditions restrict budbreak and is rarely experienced in tropical or sub-tropical tree fruit production, where temperatures are usually above the threshold to induce budbreak. Chilling is required to enable the transition from dormancy to growth (Pereira, Angelocci, & Sentelhas, 2002). Chilling is usually effective at temperatures below 7°C (Luedeling, 2012). Under natural conditions, the end of the dormancy period and the ability to resume growth in temperate fruit trees are mediated by chill accumulation (Alburquerque, García-Montiel, Carrillo, & Burgos, 2008; Gariglio, Weber, Castro, & Micheloud, 2012; Oukabli & Mahhou, 2007; Rahemi & Pakkish, 2009; Segantini, Leonel, Cunha, Ferraz, & Ripardo, 2014). The main challenge for temperate fruit production in the tropics is to overcome the dormancy period (Erez, 2001).

For cultivation in regions that experience winters with non-chilling temperatures, it is necessary to use species and cultivars adapted to these environmental conditions. According to Hauagge (2000), two factors determine the adaptation of temperate fruit trees in the tropics: 1. the ability of a given cultivar to break dormancy, bloom, set fruit, and grow satisfactorily, either naturally or with targeted horticultural practices; and 2. the ability to produce quality fruits at temperatures that are often warmer than in their region of origin. Naturally, many temperate fruits growing in subtropical or tropical regions are not able to fulfill these two requirements. There are horticultural strategies to increase the success of using apple and pear cultivars with low chilling requirements. These include the interruption of irrigation during the winter period to stimulate bud break, chemical defoliation of the orchard to stimulate bud break, the densification of orchards, and double pruning (green and production) (Alcântara, Pio, Souza, Bisi, Bettiol Neto, & Farias, 2018). These techniques allow fruit production by temperate fruit trees in marginal environmental conditions (Campagnolo & Pio, 2012; Souza, Alvarenga, Pio, Gonçalves, & Patto, 2013; Tadeu et al., 2015; Souza et al., 2017).

Improving the suitability of some temperate fruit species to tropical environments has involved changes in the genetic structure of populations, which are determined mainly by genetic drift, mutation and natural and/or artificial selection as well as interactions among those factors (Perez-Gonzalez, 2000). In this sense, breeding programs play a critical role in the expansion of temperate fruit trees in the tropics, primarily through the selection of low chilling requirement genotypes (Barbosa et al., 2010; Bettiol Neto et al., 2014).

## Current situation of temperate fruit cultivation in the tropics

In the past few decades, the cultivation of temperate fruit trees has expanded to regions that have been traditionally unsuitable for production in relation to its natural habitat. According to Erez (2001), one of the main production limitations in the tropics is to overcome the dormancy period typical of temperate tree fruit species. From the introduction of cultivars, a better understanding of the underlying physiology of dormancy (Arora et al., 2003) and the development of management strategies for the tropical production of temperature tree fruit species have become possible (Barbosa, Veiga, Pommer, Pio, & Chagas, 2008). Consumer demand for temperate fruit in the tropics has increased in recent years, is likely to increase in the future (Table 1) and may contribute to growing local demand for these types of fruit.

**Table 1.** Total production (tons) of the main temperate fruit trees in tropical and subtropical countries in 1990 and 2015.

| Countries | Apple | | Pear | | Peach+plum | | Grapevine | |
|---|---|---|---|---|---|---|---|---|
| | 1990 | 2015 | 1990 | 2015 | 1990 | 2015 | 1990 | 2015 |
| Afghanistan | 16,867 | 59,850 | 2,296 | 2,900 | 13,574 | 13,400 | 365,000 | 397,000 |
| Algeria | 38,941 | 378,637 | 24,461 | 234,274 | 15,336 | 156,890 | 262,794 | 560,562 |
| Bolivia | 7,970 | 1,938 | 3,660 | 1,865 | 30,333 | 33,636 | 18,825 | 25,048 |
| Brazil | 543,515 | 1,279,124 | 16,839 | 16,397 | 102,791 | 222,402 | 804,774 | 1,355,461 |
| Colombia | - | 1,638 | - | 17,799 | - | 18,476 | 15,913 | 37,380 |
| Ecuador | 33,224 | 9,500 | 5,404 | 7,764 | 4,323 | 8,282 | 140 | 414 |
| Egypt | 61,719 | 493,119 | 47,459 | 44,713 | 37,442 | 273,256 | 584,694 | 1,360,251 |
| India | 1,093,900 | 1,777,200 | 157,987 | 336,049 | 70,000 | 244,000 | 408,170 | 880,700 |
| Iran | 1,523,980 | 1,662,430 | 147,690 | 153,390 | 70,664 | 496,130 | 1,423,766 | 2.255,672 |
| Iraq | 75,000 | 39,601 | 8,500 | 12,789 | 29,000 | 1,452 | 455,000 | 212,649 |
| Israel | 112,700 | 131,474 | 24,400 | 30,935 | 41,200 | 65,763 | 95,000 | 95,075 |
| Jordan | 11,896 | 28,770 | 698 | 2,141 | 9,044 | 20,833 | 45,726 | 29,683 |
| Mexico | 456,538 | 584,655 | 19,060 | 24,986 | 161,162 | 227,421 | 428,898 | 307,147 |
| Morocco | 221,000 | 444,861 | 36,400 | 41,062 | 35,200 | 85,204 | 232,000 | 344,334 |
| Pakistan | 243,000 | 525,855 | 31,100 | 19,291 | 21,800 | 52,579 | 32,845 | 64,413 |
| Paraguay | 723 | 732 | 216 | 246 | 1,894 | 1,496 | 22,336 | 1,936 |
| Peru | 118,416 | 143,861 | 6,723 | 4,821 | 39,958 | 44,052 | 55,431 | 280,468 |
| South Africa | 430,344 | 724,232 | 195,237 | 368,495 | 145,332 | 164,231 | 1,317,920 | 1,743,496 |
| Tunisia | 41,800 | 126,000 | 25,000 | 66,000 | 35,000 | 117,000 | 77,350 | 97,000 |
| Venezuela | - | - | - | - | 9,000 | 40,693 | 12,475 | 17,870 |
| Zimbabwe | 6,345 | 6,196 | 386 | 128 | 1,186 | 1,009 | 1,723 | 3,132 |
| World | 5,037,878 | 8,419,673 | 753,516 | 1,386,045 | 874,239 | 2,288,205 | 6,660,780 | 7,814,021 |

Source: FAOSTAT (2017).

Brazil is the third largest fruit producer in the world and produces more than 41 million tons of fruit per year on approximately 2 million hectares (Table 1). Domestic consumption is the primary destination, but

Brazil also accounts for 2% of global trade in the sector. Temperate tree fruit is produced on 147 thousand hectares (7.24% of total fruit production) and totals 3.27 million tons (7.98% of total production) (FAO, 2017). Nevertheless, temperate tree fruit accounts for approximately 37% of the total value of fruit exports in the country (Fachinello, Pasa, Schmtiz, & Betemps, 2011). In the last 48 years, temperate fruit production has had a major impact on the Brazilian economy, increasing in production from 732,359 to 2,102,534 tons (347.47%) and in area from 94,339 to 147,328 hectares (56.16%). This shows a large increase in orchard productivity in the last five decades, from 7.76 t $ha^{-1}$ to the current 14.27 t $ha^{-1}$ (Table 2).

**Table 2.** Total production (tons) and area (hectares) of the primary temperate fruit trees in Brazil in the last 50 years (1970-2015). FAO (2017).

| Fruit tree | Production (tons) | | | | | Area (hectares) | | |
|---|---|---|---|---|---|---|---|---|
| | 1969 | 1984 | 1999 | 2016 | Growth (%) | 1969 | 2016 | Growth (%) |
| Grape | 483,443 | 603,172 | 931,500 | 1,453,889 | + 200.73 | 59,744 | 78,767 | +31.84 |
| Apple | 28,864 | 255,773 | 937,715 | 1,378,617 | + 4,676.25 | 2,770 | 37,121 | + 1,240 |
| Peach | 97,434 | 111,591 | 131,300 | 211,109 | + 116.66 | 12,352 | 18,210 | + 47.42 |
| Persimmon | 20,849 | 41,915 | 64,096 | 182,280 | + 774.28 | 3,419 | 8,358 | + 144.45 |
| Fig | 21,991 | 23,911 | 16,570 | 28,044 | + 27.52 | 3,053 | 2,807 | - 0.08 |
| Pear | 59,217 | 26,697 | 16,474 | 19,089 | - 67.76 | 4,659 | 1,474 | - 69.36 |
| Quince | 18,919 | 10,686 | 4,879 | 570 | - 96.98 | 8,342 | 111 | - 98.66 |
| Olive | 1,042 | 95 | 62 | 300 | - 71.20 | * | 100 | - |
| Strawberry | 600 | 2,000 | 2,270 | 3,200 | + 433.33 | * | 380 | - |
| Temperate | 732,359 | 1,075,840 | 2,102,534 | 3,277,098 | + 347.47 | 94,339 | 147,328 | + 56.16 |
| Tropical | 10,063,464 | 22,378,688 | 35,495,816 | 37,746,513 | + 275.08 | 655,290 | 1,886,225 | + 187,84 |
| Total | 10,795,823 | 23,454,528 | 37,598,350 | 41,023,611 | + 279.99 | 749,629 | 2,033,553 | +171.27 |

*No statistical data.

Among the temperate tree fruit species grown in Brazil, apple trees showed the highest growth in production, with total production increasing from 28,864 to 1,378,617 tons (4,676.25%) in the last 50 years. Initially, apples were only produced in the South and Southeast regions in Brazil, where the climate is more temperate. However, apples were not traditionally produced in the Northeast, which is characterized by a tropical climate. Recently, apple production has expanded to these regions in the northeast of Brazil. This expansion was driven by the development of low-chilling apple cultivars for tropical and subtropical regions by the Agronomic Institute of Campinas (IAC) and the Agronomic Institute of Paraná (IAPAR), in addition to the use of horticultural techniques developed in the last few decades (Chagas et al., 2012). Fachinello et al. (2011) identified the factors responsible for this expansion of apple tree cultivation as technological developments, expertise and infrastructure, and the use of recognizable cultivars (Gala, 58% and Fuji, 36%) with lower chilling requirements that are capable of meeting the consumer's requirements.

In addition to apple trees, there has been a significant increase in the production of other temperate fruits in Brazil in recent decades, such as the production of persimmons (774.28%), strawberries (433.33%), grapes (200.73%), and peaches (27.52%). However, there was also a decrease in production of quince (96.98%), olives (71.20%), and pears (67.76%). These declines occurred for different reasons and were strongly offset by increases in production in the other tree fruit described above. Quince was a critical industrial crop in the 1930s in the Serra da Mantiqueira region of Minas Gerais State, Brazil (Bettiol Neto, Pio, Sanches, Chagas, Cia, Chagas, and Antoniali, 2011). Pear and olive production has gradually declined because of a marked decrease in the supply and quality of the produced fruits in relation to fruits produced abroad (Pio et al., 2007). According to Fachinello et al. (2011), the increase in tree fruit production depends on the development of new cultivars and horticultural strategies that provide solutions to overcome low chilling requirements and ensure stable budbreak, bloom, and fruit set that ensures continuous production in regions that experience high temperature oscillations during the winter.

In contrast to the challenges, there are benefits to producing temperate fruit in non-traditional regions. According to Guedes et al. (2017), blackberries cultivated in high altitude tropical climates contain elevated levels of photochemicals, which may contribute to natural antioxidant properties. Maro, Pio, Guedes, Abreu, & Curi (2013) and Maro, Pio, Guedes, Abreu, & Moura (2014) reported that raspberry production in a high altitude tropical climate results in increased fruit size and a high sugar: acid ratio. Curi et al. (2016) observed that strawberry cultivars from different subtropical regions had lower acidity than the acidity levels reported in the literature. According to Maro et al. (2014) and Moura et al. (2012), this variation can occur because the climatic conditions in the southern part of the state of Minas Gerais, Brazil, have elevated temperatures and a longer photoperiod during the growing season. However, these variations can also be explained by factors such as variety, cultivar, harvest season, maturity, ripening stage and/or soil conditions (Faniadis, Drogoudi, & Vasilakakis, 2010).

Despite the development of management strategies to improve the production of temperate fruit trees in mild winter regions, there are other challenges that need to be addressed. According to Souza et al. (2017), research aimed at methods that increase fruit set can provide an increase in yield in tropical and subtropical regions. Souza, Pio, Coelho, Rodas, & Silva (2015) mentioned that, although temperate fruit growing areas are expanding to subtropical regions, there is still a need to improve cultural management. This is especially true for determining their mineral nutrient requirements, as well as to establish parameters for the visual diagnosis of mineral nutrient deficiencies.

## Dormancy of temperate fruit trees

Temperate deciduous trees have adapted naturally to regions with well-defined seasons, which are suitable for growth during the spring and the summer, and temperatures close to zero or below freezing in the autumn and the winter (Dalastra, Pio, Campagnolo, Dalastra, Chagas, & Guimarães, 2009). To survive this period of low winter temperatures, trees have developed a mechanism that limits vegetative growth and increases the ability to withstand freezing temperatures called dormancy (Leite, Petri, & Couto, 2014). The term "dormancy" refers to the total period of rest, from the cessation of growth and bud set to bud break and the resumption of growth, which consists of the appearance of the first leaves emerging from the bud. Dormancy is a complex phenomenon with differentiated physiological and biochemical characteristics among genotypes and environments. During dormancy, temperate fruit trees reduce their metabolic activity and show no visible vegetative growth to protect plant tissue that is sensitive to unfavorable climatic conditions (Campoy, Ruiz, & Egea, 2011). At this stage, meristems are protected from adverse environmental conditions that may damage the flower or leaf primordia, such as below freezing temperatures for extended periods (Pola, Bruna, Back, & Moreto, 2016). Temperature and photoperiod are critical contributors to dormancy induction (Kalcsits, Silim, & Tanino, 2009). However, for budbreak, temperature is considered the main environmental factor involved in the process (Arora et al., 2003; Leite et al., 2014).

Dormancy has been studied in several temperate fruit tree species with the aim of better understanding the physiological mechanisms involved in dormancy induction, maintenance, and bud break (Arora et al., 2003). At the beginning of spring, the buds undergo a series of successive phenological stages. These phenological changes have been intensively studied and classified according to their development, from dormancy to fruiting (Fujisawa & Kobayashi, 2010; Guédon & Legave, 2008; Oliveira, Lopes, Silva Matos, & Cavalcante, 2013). The dormancy phases of temperate fruit trees are divided into three types or phases: paradormancy, ecodormancy, and endodormancy (Lang et al., 1987; Leite et al., 2014). It is assumed that the inhibition of growth is because of unfavorable environmental conditions (ecormancy). With the advancement of autumn, the plant exhibits a change in hormonal balance, reducing growth-promoting hormones and increasing inhibitors, notably gibberellins and abscisic acid, respectively, and dormancy is induced (Leite et al., 2014). Other types of dormancy include the influence of another plant organ on bud phenology (paradormancy) or biochemical and physiological events that occur inside the bud that inhibit bud break (endodormancy) (Lang et al., 1987).

Under conditions where chilling temperatures (in general, below 7°C and above 0°C) or the length of chilling is insufficient, the plant cannot transition from a dormant to non-dormant growth stage. This limits the flowering and bud break of tree fruit species, making flowering and vegetative growth erratic. Inconsistencies in the timing of bud break and flowering can limit vertical growth, make the tree difficult to manage, limit fruit set and increase the number of malformed fruit. Furthermore, under severe conditions, insufficient chilling can lead to plant death (Scorza & Sherman, 1996). This is best demonstrated when apple cultivars of higher or lower chilling requirements are grown in the tropics. Low chilling cultivars such as 'Eva', 'Princesa', and 'Baronesa' are well adapted to production in subtropical regions because of the regularity of bud break, flowering and fruit production. On the other hand, some cultivars such as 'Imperial Gala' and 'Daiane' that have greater chilling requirements, are less consistent in bud break, reducing tree health and productivity (Chagas et al., 2012). Another important factor contributing to the suitability of temperate fruit tree cultivars to production in the tropics is the increase in the flowering period and consequently, in the harvest period (Bettiol Neto et al., 2014)

The most efficient method for overcoming dormancy is to use cultivars with low chilling requirements. In addition to the use of cultivars with low chilling requirements, there are some cultural management strategies that can minimize the effects of low chilling hours on bud break and flowering when the chilling requirement has only been partially satisfied (Leite et al., 2014).

## Chilling requirements

The amount of chilling needed to overcome dormancy varies depending on the species and cultivar. Additionally, there is also significant variation among bud types and location within the tree. Nevertheless, floriferous buds generally have lower chilling requirements compared to vegetative ones, and terminal buds generally have lower chilling requirements than the axillary buds (Leite et al., 2014).

Currently, there are several methods to quantify chilling hours experienced at a given location. Among them, the most commonly used is the chilling unit method, which consists of quantifying the number of chilling hours below 7.2°C. In addition, there are other methods that include temperatures above 7.2°C, such as the Utah (1.5 - 12.4°C), the North Carolina (1.6 - 13°C), and the weighted chilling hours (3 - 10°C) methods (Citadin, Raseira, Herter, & Silveira, 2002). According to Citadin et al. (2002), the chilling unit method has been used less frequently since temperatures above 7.2°C are also effective, and it is believed that temperatures below 12°C still contribute to dormancy break. According to Chavarria et al. (2009), temperatures up to 15°C still have a chilling effect on dormant peach buds.

The variability in chilling requirements among species, cultivars, wild species, and interspecific hybrids is generally wide (Hauagge & Cummins, 1991). There are several species with low chilling requirements, such as persimmon trees (*Diospyros* sp.), blackberry bushes (*Rubus* spp.), the fig tree (*Ficus carica*), the apple tree (*Malus domestica*), the quince tree (*Cydonia oblonga*), the pear tree (*Pyrus* spp.), the peach tree (*Prunus persica*), and grapevines (*Vitis* spp.), which can be grown in the tropics due to the naturally low chilling requirement of the species, breeding, and the use of appropriate horticultural management. According to Hauagge (2000), although the cherry tree (*Prunus avium*) and the apricot tree (*Prunus armeniaca*) have low chilling requirements, these species are also susceptible to mid-winter deacclimation and budbreak that can lead to frost damage or poor fruit set, making them unsuitable for sub-tropical and tropical climates.

## Induction of bud break

Uniform bud break and flowering is essential to improve tree productivity and growth as well as to reduce the length of time for harvest to occur. The use of chemical products to induce bud break and flowering can be a useful alternative to minimize problems of insufficient chilling in temperate fruit trees (Hawerrothet et al., 2009; Coletti, Nienow, & Calvete, 2011). Hydrogen cyanimide can be used in addition to or combined with mineral oil (Jaldo, Berettoni, Ale, & Forns, 2009; Campoy et al., 2011). The benefit of using this approach is that it provides increased productivity. In some years and regions, productivity can be drastically reduced if plant chilling requirements are not met and bud break and flowering are inconsistent (Petri, Leite, Couto, & Francescatto, 2011).

Treatments, such as cyanimide that induce bud break, become more efficient as the chilling hours accumulated increases. Therefore, even with these treatments, low chilling continues to have a negative effect on productivity in low chill years and regions (Miele, Rizzon, & Dall'agnol, 1998). Additionally, the use of these products can negatively impact fruit quality. Fruit quality is higher in orchards that are not treated with bud break inducers compared to treated orchards. In Brazil, natural products such as garlic (*Allium sativum*) extract have also been used to overcome dormancy in temperate fruit trees and, when applied together with mineral oil, it has a similar effect to the conventional treatment with hydrogen cyanamide (Botelho, Pavanello, Pires, Terra, & Muller, 2007). This provides an organically compatible option for managing bud break for organic temperate tree fruit producers in regions with low chill unit accumulation.

In addition to the choice of cultivars with low chilling requirements and the use of chemical bud break stimulants, other techniques can be used to overcome low chilling conditions. These include artificial cold treatments to increase chilling and induce more uniform bud break. Many treatments involve managing vegetative growth to promote the reallocation of photoassimilates into flower bud production. Among them, vegetative growth can be controlled by chemical growth inhibitors, such as prohexadione calcium or copper oxychloride, or by limiting nitrogen fertilizer applications to avoid excessive growth. The bending of branches can stimulate the bud break of lateral buds and pruning after harvest can reduce vigor and promote the reallocation of photoassimilates. Lastly, fruit thinning can be used to avoid overproduction and the weakening of plants (Leite et al., 2014). According to Hauagge (2000), although it is possible to break dormancy with chemical substances, growth, production, and quality are generally lower than those obtained in adapted cultivars. According to Lopes, Oliveira, Silva, and Cavalcante (2013), there are other possible techniques to produce fruit in semi-arid regions and avoid such issues, such as the induction of bud break through the interruption of irrigation or manual leaf removal. These treatments can be successfully followed by chemical treatment to induce bud break.

## Advances in the breeding of temperate tree fruit

With regard to climatic aptitude, fruit trees have been traditionally classified as tropical, subtropical, or temperate. However, most current knowledge from origin centers of different species, technological advances in orchard management and fruit conservation, and especially breeding have created cultivars for temperate tree fruit species that are better suited to tropical and subtropical regions (Pereira & Kavati, 2011).

According to Perez-Gonzalez (2000), breeding programs take the following steps for the development of cultivars with specified desirable traits suitable for subtropical and tropical growing regions: a) development and analysis of genetic resources of temperate fruit trees existing in the world with the possibility of suitability for the tropics and subtropics; b) recombination of contrasting and complementary "gene pools", using parents with very low chilling requirements; c) selection in close association with fruit growers and marketers to optimize breeding efficiency and best meet grower and consumer demands for desirable traits; and d) screening for the suitability for tropical and subtropical climates beginning with propagation, continuing with the clonal behavior during the first years in the field and, most importantly, establishing criteria for the evaluation of inter-annual productivity and fruit quality. Issues related to the selection of cultivars with improper chilling requirement can affect the productive potential of tree fruit cultivars, especially under climatic conditions with mild winters (Ruiz et al., 2007). Thus, the correct choice of cultivars adapted to the climatic conditions of the place is extremely important before planting an orchard.

The existence of genetic variability in chilling requirements is a determining factor for the success of breeding programs that aim to create cultivars adapted to subtropical winter conditions. In this sense, a better understanding of the chilling requirement of a certain genotype together with temperature information from the region where it will be planted are fundamental to the success of peach tree cultivation (Wagner Júnior et al., 2009).

Genetic improvement programs suggest cultivars with low chilling requirements; however, there are other intrinsic characteristics targeted by these programs, such as the selection of late flowering cultivars in regions with frost risks (Citadin, Bassani, Danner, Mazaro, & Gouvêa, 2006). These traits need to be combined with desirable fruit quality traits that allow the production of fruit that is productive in these climates but also equivalent in quality to fruit produced in temperate regions.

## Agroclimatic zoning

Agroclimatic zoning is a very useful and highly successful tool for the planning of temperate fruit orchards. It provides information that allows cultivar and management decisions that are best suited to those zones. Studies of climatological trends and parameters of climatic variability are widely applied in the planning of agricultural activities, agricultural zoning (Cardoso et al., 2012) and in the forecasting of future scenarios (Carbonieri & Morais, 2015). Numerous studies have been developed aiming to simulate the production of temperate fruit trees in Brazil in atypical regions based on the evaluation of climatic parameters, according to Caramori et al. (2008), Bardin-Camparotto, Pedro Júnior, Blain, & Hernandes (2014), Pommer, Mendes, Hespanhol-Viana, & Bressan-Smith (2009), and Sarmento, Flores, Weber, Hasenack, & Pötter (2008).

Currently, the main producing regions of temperate fruit trees in Brazil are located in climates referring to Cfa (humid subtropical hot summer), Cfb (humid subtropical mild summer), Cwa (humid subtropical dry winter and hot summer) and Cwb (subtropical humid dry winter and mild summer) that are located mainly in the South and Southeast regions. However, in recent years, the cultivation of temperate fruit tree species has crossed this agricultural frontier and is cultivated in places with high annual temperatures. However, this generally occurs above 700 m altitude and includes the cultivation of vines in the savanna of the State of Goiás (Aw - tropical dry winter); wine grape, persimmon, apple and pear tree in the Submédio do Vale do São Francisco, semiarid region in the State of Pernambuco (Bs - very hot semiarid); apple, wine grape and plum in the Chapada da Diamantina, in the State of Bahia (Aw - tropical dry winter); and apple and pear production in the Serra da Ibiapaba in the State of Ceará (Aw - tropical dry winter).

## Conclusion

Producing temperate fruit trees in the tropics is a great challenge due to low chilling conditions of this climate. However, in the last five decades the production has expanded to these regions because of the availability of cultivars with low chilling requirements and the development of practices to limit the impact of low chilling. Still though, there is a need for the development of new strategies to induce dormancy and bud break more uniformly. In the future, the development and adoption of cultivars with lower chilling requirements is critical to the success of temperate tree fruit production in the tropics.

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