REVISTA BRASILEIRA DE FRUTICULTURA
Published by the Brazilian Society of Fruit Crops
ISSN 0100-2945

Crop Production - Original Article - Edited by: Adriane Marinho de Assis

Phenological cycle and thermal accumulation in the genotypes of sweet orange in Southern Brazil

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Abstract: The aim of this work was to study the phenology of several sweet orange cultivars and their relationship with the accumulated degree-day (ADD), under the conditions of the Depressão Central of Rio Grande do Sul, in Southern Brazil. For this, 25 genotypes were evaluated for three consecutive growing seasons between 2015 and 2018. The experiment was carried out in a Citrus Collection located in municipality of Eldorado do Sul, RS, Brazil. The ADD was calculated for each interval between the phenological stages, as well as for the entire cycle. The first one, swelling of the buds, was concentrated between mid-July and early August. Sprouting in winter increased the risk of frost damage. Full bloom occurred between August 28 and September 22, when the orange trees 'Cabula', 'Rubi', 'Lima Verde' and 'Folha Murcha' were the first to bloom and 'Sanguinea', 'Salustiana', 'Midknight' and 'Jaffa' the last. The last stage evaluated, the skin color change of the fruits, occurred between the beginning of April and the end of May, with 2,306.4 to 2,619.4 ADD, since the beginning of sprouting. The orange trees showed different behavior when compared between genotypes and between years. Two groups of cultivars were defined: early and late.

Index terms: Phenology, BBCH Scale, Degree-day, *Citrus sinensis* (L.) Osbeck.

Ciclo fenológico e acúmulo térmico em genótipos de laranjeiras-doces no Sul do Brasil

Resumo: O objetivo deste trabalho foi estudar a fenologia de diversas cultivares de laranjeiras-doces e sua relação com os graus-dia acumulados (GDA), nas condições da Depressão Central do RS. Para isso, 25 genótipos foram avaliados por três sa-

Rev. Bras. Frutic., v.46, e-033 DOI: *https://dx.doi.org/10.1590/0100-29452024033*
Received 04 Mar, 2023 ● Accepted 12 Sep, 2023 ● Published Jan/Feb, 2024. Jaboticabal - SP - Brazil.

fras consecutivas, entre 2015 e 2018, conforme a escala fenológica BBCH. O experimento foi conduzido em Coleção de Citros localizada no município de Eldorado do Sul-RS, Brasil. Calcularam-se, os GDAs para cada intervalo entre os estádios fenológicos, bem como para todo o ciclo. O primeiro deles, inchamento das gemas, aconteceu concentrado entre meados de julho e início de agosto. A brotação, ainda no inverno, aumentou riscos de danos por geadas. O pleno florescimento ocorreu entre 28 de agosto e 22 de setembro, onde as laranjeiras 'Cabula', 'Rubi', 'Lima Verde' e 'Folha Murcha' foram as primeiras; e 'Sanguinea', 'Salustiana', 'Midknight' e 'Jaffa', as últimas. O último estádio avaliado, mudança da cor da casca dos frutos, ocorreu entre o início de abril até fins de maio, com 2.306,4 a 2.619,4 GDAs, desde o início da brotação. As laranjeiras apresentaram comportamento distinto, quando comparadas entre os genótipos e entre os anos. Definiram-se dois grupos de cultivares: precoces e tardias.

Termos para indexação: Fenologia, Escala BBCH, Graus-dia, *Citrus sinensis* (L.) Osbeck.

Introduction

The cultivars of sweet orange trees, *Citrus sinensis* (L.) Osbeck, are the most explored citrus group in the world. Brazil is the largest producer of oranges in the world, with about 16.2 million tons in 2021, representing 21,5% of world production (FAO, 2023). Most of that will be made into juice (NEVES; TROMBIN, 2017). The citrus industry is the source of income for a large number of families and has great socio-economic importance in Rio Grande do Sul (RS) (SULZBACH et al., 2016). The 'Valencia' orange is the predominant cultivar of this State. In a historical context, citriculture has proved vulnerable to a series of phytosanitary problems and, even so, in this temporal view, little diversification of cultivars was noticed in commercial orchards (JOÃO; CONTE, 2018).

The regional evaluation of cultivars is essential to identify the phenological behavior and indicate the recommendation for cultivation (RAMOS, 2015; BERGAMASCHI, 2017). Moreover, some pests and diseases cause greater damage in certain stages of development, especially when the tissues are young, and preventive actions can be taken in these phases (LEITE JR, 1990).

The phenology of plants varies according to the various environmental phenomena to which they are subjected (BERGAMASCHI, 2017). Citrus in subtropical conditions, has air temperature as the main meteorological element of influence (MANERA et al., 2012), since the effects of the photoperiod seem to be null (GRAVINA, 2014). Taking this into account, even climate changes tend to alter the phenological behavior of plant species (RAMOS; JONES, 2019; WU et al., 2019;).

The aim of this work was to study the phenological behavior of several sweet orange genotypes and their relationship with thermal accumulation, under the conditions of the Depressão Central of Rio Grande do Sul, Brazil.

Materials and Methods

The orchard used in this study was the Citrus Collection, which is located at the Experimental Agronomic Station of the Federal University of Rio Grande do Sul (EEA/UFRGS), located in the municipality of Eldorado do Sul - RS, whose geographical coordinates are: latitude 30°06'59" South and longitude 51°40'02" West, with an average altitude of 60 m above sea level.

The soil is classified as a *Argissolo Vermelho distrófico típico* according to the Brazilian soil classification system (SANTOS et al., 2018), i.e., a Rhodic Ultisol, with flat and wavy reliefs. The climate in the region is Cfa (humid subtropical) according to the Köppen climate

classification. The annual mean temperature is 18.8 °C, varying between 13.0 and 24.2 °C between the coldest and the warmest month of the year. The mean annual precipitation is 1,455 mm and the mean relative humidity of the air is 79% (BERGAMASCHI et al., 2013).

In the 2015-16, 2016-17 and 2017-18 growing seasons, the phenological behavior of 25 orange genotypes (*Citrus sinensis* (L.) Osbeck) was evaluated, including: 'Bahia', 'Cabula', 'Campo Alto', 'Folha Murcha', 'Hactur', 'Hamlin', 'Liberato Salzano', 'Lima Verde', 'Natal', 'Newhall', 'Piralima', 'Rubi', 'SCS454 Catarina', 'Seleta Frank', 'Lima Sorocaba', 'Valencia', 'Valencia Late', 'Valencia V1' and 'Valencia V5', grafted on the citrus tree 'Fepagro C13' [*C. sinensis* x *Poncirus trifoliata* (L.) Raf.] and, 'Jaffa', 'Lue Gim Gong', 'Midknight', 'Navelina', 'Salustiana' and 'Sanguinea', on *P. trifoliata*. Each genotype was represented by three useful plants, that have been fully evaluated, taking into account the criterion of the stage found in at least 50% of the developing organs. The spacing of the plants was 3.5 x 7.0 m, and the orchard was established in 2008.

The evaluations were carried out weekly, between July and November, and every two weeks, between December and May, for each growing seasons. The phenological scale *Biologische Bundesanstalt, Bundessortenamt und Chemische industrie* (BBCH) was used as the basis for citrus cultivation, elaborated by Agustí et al. (1995). The first phenological stage considered in this study was stage 51 (bud swelling), according to the BBCH scale. The monitoring of the phenological stages occurred until the time when the color of the bark began to change (stage 81). All evaluated phenological stages are described in Figure 1.

Figure 1. Phenology of orange trees, according to the BBCH scale for citrus (Agustí et al., 1995). Images by author.

A Meteorological Station installed in the center of the experimental orchard, collected temperature and precipitation data during the three seasons evaluated (Figure 2).

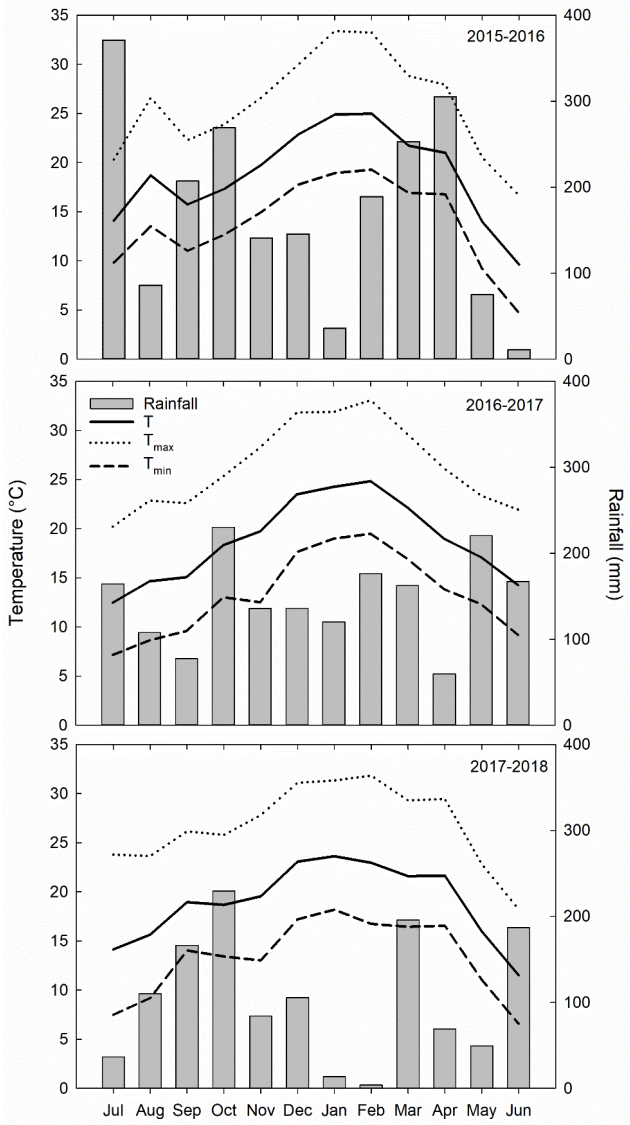

Figure 2. Accumulated monthly precipitation (mm) and monthly mean temperatures (T), mean minimum temperature (T_{min}) and mean maximum temperature (T_{max}) (°C), for the period of three growing seasons (2015-16, 2016-17, 2017-18) in the EEA/UFRGS Citrus Collection, Eldorado do Sul / RS, Brazil.

The daily data of mean temperature (T_{mean}), minimum temperature ($T_{mín}$) and maximum temperature (T_{max}) were used to calculate the degree-days (GD), through equations proposed by Ometto (1981) and according to three possible situations during the day, in the conditions of Rio Grande do Sul:

A) Temperature between T_b and T_B:

$$GD = \frac{(T_{min} - T_b) + (T_{max} - T_{min})}{2}$$

B) T_{min} below the T_b and T_{max} below the T_B:

$$GD = \frac{(T_{max} - T_b)^2}{2\,(T_{max} - T_{min})}$$

C) T_{max} above the T_B and T_{min} above the T_b:

$$GD = (T_{min} - T_b) + \left(\frac{T_{max} - T_{min}}{2}\right) - \left[\frac{(T_{max} - T_B)^2}{2\,(T_{max} - T_{min})}\right]$$

in which lower basal temperature (T_b) was 12.8 °C and upper basal temperature (T_B) was 36.0 °C (STENZEL et al., 2006).

During the growing seasons, the mean date (MD) and standard deviation (SD) were calculated for the occurrence of each phenological stage of each orange genotype evaluated (Table 1). In addition, the mean accumulated degree-days (ADD) was calculated, and so was its SD, for each interval between the stages (Table 2). In each growing season, the harvest was carried out when the fruit was in horticultural maturation (KYRIACOU; ROUPHAEL, 2018), through subjective criteria, to serve the fresh consumption market. The days interval between stage 81 and harvest (MDI 81-H) were also calculated. Analysis of variance (ANOVA) was also carried out, followed by the Scott-Knott and Dunnett mean tests for the mean day interval (MDI) and ADD data between stages 51 - 81, 51 - 65 and 65 - 81, from the BBCH scale (Table 3) and MDI 81-H (Table 4).

Results and Discussion

The beginning of spring sprouting, characterized in this work by the swelling of the buds - stage BBCH 51, was concentrated in the month of July (between MD = July 11 and MD = July 20) for most of the materials studied (Table 1). For the cultivar 'Jaffa', the last to start sprouting, this phase occurred at the beginning of August (MD = August 5). The orange 'Rubi' was the first to sprout.

Table 1. Mean dates (MD) and standard deviation (SD) of occurrence of the phenological stages of the BBCH scale[1], in orange trees from the Citrus Collection of the Experimental Agronomic Station - UFRGS, in the 2015-16, 2016-17 and 2017-18 growing seasons. Eldorado do Sul, RS, Brazil.

Cultivars	51	53	55	56	59	65	69	72	73	74	81
'Rubi'	7/11[2] ± 6	7/16 ± 6	7/24 ± 9	8/6 ± 13	8/22 ± 10	8/29 ± 8	9/5 ± 7	9/15 ± 10	10/10 ± 8	11/5 ± 17	4/11 ± 3
'Cabula'	7/13 ± 4	7/17 ± 4	7/26 ± 6	8/9 ± 10	8/20 ± 8	8/28 ± 7	9/5 ± 7	10/5 ± 5	10/14 ± 4	10/30 ± 7	4/15 ± 8
'Piralima'	7/14 ± 4	7/22 ± 7	7/30 ± 8	8/16 ± 4	8/26 ± 8	9/4 ± 5	9/10 ± 4	10/1 ± 7	10/14 ± 4	11/5 ± 13	4/15 ± 3
'Lima Verde'	7/14 ± 4	7/20 ± 4	7/31 ± 9	8/15 ± 5	8/27 ± 7	8/31 ± 8	9/9 ± 6	9/28 ± 6	10/11 ± 6	10/30 ± 8	4/15 ± 3
'Hamlin'	7/15 ± 5	7/21 ± 6	8/2 ± 10	8/9 ± 10	8/22 ± 10	9/1 ± 6	9/8 ± 5	9/28 ± 6	10/14 ± 4	10/30 ± 8	4/8 ± 5
'Valencia'	7/15 ± 4	7/22 ± 4	7/31 ± 4	8/11 ± 6	8/24 ± 6	9/1 ± 7	9/9 ± 7	9/30 ± 8	10/14 ± 4	10/30 ± 8	5/6 ± 2
'Valencia V1'	7/15 ± 2	7/20 ± 1	8/1 ± 3	8/15 ± 4	8/27 ± 7	9/5 ± 7	9/13 ± 7	9/30 ± 8	10/14 ± 4	11/8 ± 13	5/21 ± 8
'SCS454 Catarina'	7/17 ± 5	7/25 ± 7	8/6 ± 8	8/14 ± 7	8/27 ± 7	9/4 ± 7	9/12 ± 7	9/30 ± 8	10/17 ± 5	11/1 ± 7	4/23 ± 5
'Newhall'	7/17 ± 6	7/27 ± 5	8/3 ± 6	8/17 ± 3	8/28 ± 5	9/5 ± 7	9/12 ± 7	10/14 ± 4	10/14 ± 4	11/5 ± 13	4/12 ± 6
'Folha Murcha'	7/17 ± 4	7/26 ± 6	8/6 ± 2	8/15 ± 4	8/23 ± 6	8/31 ± 5	9/10 ± 8	9/30 ± 8	10/14 ± 4	11/8 ± 13	5/27 ± 8
'Bahia'	7/17 ± 7	7/23 ± 9	7/28 ± 10	8/4 ± 12	8/21 ± 8	9/1 ± 4	9/12 ± 7	10/2 ± 8	10/11 ± 6	10/28 ± 12	4/23 ± 5
'Seleta Franck'	7/18 ± 5	7/24 ± 6	7/29 ± 8	8/10 ± 10	8/22 ± 10	9/1 ± 7	9/8 ± 5	9/17 ± 8	10/14 ± 4	11/5 ± 13	4/8 ± 5
'Campo Alto'	7/18 ± 3	7/25 ± 4	8/3 ± 2	8/13 ± 6	8/25 ± 8	9/3 ± 9	9/10 ± 8	9/28 ± 9	10/14 ± 4	11/8 ± 13	4/27 ± 8
'Natal'	7/18 ± 4	7/25 ± 5	8/3 ± 5	8/14 ± 6	8/27 ± 7	9/5 ± 8	9/13 ± 8	9/30 ± 7	10/14 ± 4	11/3 ± 10	5/21 ± 8
'Navelina'	7/18 ± 6	7/24 ± 8	7/30 ± 10	8/13 ± 8	8/27 ± 8	9/7 ± 8	9/14 ± 7	10/6 ± 6	10/12 ± 3	11/12 ± 10	4/3 ± 5
'Liberato Salzano'	7/19 ± 5	7/26 ± 8	8/5 ± 12	8/16 ± 9	8/26 ± 10	9/6 ± 8	9/13 ± 7	9/30 ± 8	10/17 ± 5	11/10 ± 14	4/23 ± 5
'Hactur'	7/19 ± 2	7/28 ± 4	8/5 ± 4	8/17 ± 3	8/28 ± 7	9/5 ± 7	9/15± 10	10/6 ± 6	10/17 ± 5	11/21 ±14	5/13 ± 10
'Midknight'	7/19 ± 6	7/29 ± 8	8/6 ± 8	8/16 ± 8	8/30 ± 6	9/10 ± 8	9/17 ± 8	9/30 ± 8	10/17 ± 4	11/17 ± 5	5/23 ± 5
'Valencia V5'	7/19 ± 2	7/27 ± 4	8/4 ± 5	8/13 ± 6	8/25 ± 8	9/3 ± 8	9/10 ± 8	9/30 ± 8	10/14 ± 4	11/17 ± 5	5/21 ± 8
'Lima Sorocaba'	7/19 ± 5	7/27 ± 7	8/8 ± 8	8/17 ± 9	8/25 ± 10	9/5 ± 8	9/13 ± 8	9/28 ± 9	10/12 ± 10	11/1 ± 9	4/23 ± 5
'Salustiana'	7/19 ± 6	7/25 ± 8	8/6 ± 8	8/16 ± 8	8/28 ± 10	9/9 ± 7	9/17 ± 6	10/3 ± 6	10/16 ± 6	10/31 ± 11	4/19 ± 8
'Sanguinea'	7/19 ± 4	7/28 ± 5	8/6 ± 5	8/16 ± 5	8/29 ± 6	9/7 ± 6	9/15 ± 5	9/30 ± 8	10/17 ± 5	11/3 ± 10	4/29 ± 3
'Valencia Late'	7/20 ± 6	7/27 ± 5	8/3 ± 6	8/17 ± 3	8/28 ± 7	9/6 ± 7	9/13 ± 7	9/28 ± 9	10/14 ± 4	11/8 ± 13	5/25 ± 3
'Lue Gim Gong'	7/20 ± 4	7/27 ± 7	8/9 ± 4	8/16 ± 4	8/28 ± 7	9/6 ± 8	9/16 ± 7	10/1 ± 8	10/13 ± 3	11/6 ± 13	4/28 ± 3
'Jaffa'	8/5 ± 8	8/13 ± 9	8/22 ± 9	8/30 ± 9	9/13 ± 7	9/22 ± 6	10/1 ± 1	10/11 ± 1	10/11 ± 1	12/5 ± 4	5/22 ± 6

[1] BBCH 51 – Swollen buds, scales are visible and slightly green; BBCH 53 – Buds burst, and floral primordia are visible; BBCH 55 – Flowers become visible and are closed. BBCH 56 – Petals grow and sepals surround half the corolla; BBCH 59 – Flowers still closed, with petals forming a hollow and elongated ball; BBCH 65 – Full bloom (50% of the flowers are open); BBCH 69 – End of flowering, missing (fallen) petals and the stylus remains; BBCH 72 – Green fruit surrounded by sepals and without the stylus; BBCH 73 – Some fruits turn yellow: Beginning of the physiological fruit drop; BBCH 74 – Fruit reaches 40% of the final size, dark green color and end of the physiological drop; BBCH 81 – Beginning of fruit color change.

[2] Month/Day.

Table 2. Mean interval of accumulated degree-days (ADD, °C) for each sub period between the phenological stages of the BBCH scale[1] in orange trees of the Citrus Collection of the Experimental Agronomic Station - UFRGS, in the 2015-16, 2016-17 and 2017-18 growing seasons. Eldorado do Sul, RS, Brazil.

Cultivars	51 - 53	53 - 55	55 - 56	56 - 59	59 - 65	65 - 69	69 - 72	72 - 73	73 - 74	74 - 81
'Rubi'	11.9 ± 7.0	35.5 ± 20.8	65.0 ± 26.4	78.4 ± 21.6	27.7 ± 2.2	43.6 ± 16.0	51.6 ± 15.8	134.3 ± 42.7	185.7 ± 70.4	1,746.6 ± 31.4
'Cabula'	13.3 ± 7.9	36.1 ± 20.4	69.0 ± 21.2	61.7 ± 7.9	23.8 ± 7.3	51.7 ± 10.2	89.2 ± 69.1	123.3 ± 118.6	116.2 ± 49.6	1,839.4 ± 94.7
'Piralima'	35.2 ± 25.6	42.4 ± 32.2	71.3 ± 18.3	41.9 ± 21.5	50.1 ± 21.1	39.1 ± 20.5	107.4 ± 22.9	72.6 ± 48.4	162.7 ± 75.5	1,783.4 ± 55.0
'Lima Verde'	20.6 ± 7.6	46.8 ± 39.7	72.1 ± 28.8	55.5 ± 23.0	18.1 ± 40.2	58.8 ± 43.9	100.6 ± 23.1	70.6 ± 31.5	172.3 ± 86.9	1,793.2 ± 88.7
'Hamlin'	20.4 ± 5.4	54.5 ± 31.1	42.4 ± 21.5	62.5 ± 15.1	49.7 ± 31.2	44.5 ± 16.9	99.2 ± 23.1	90 ± 44.4	119.9 ± 64.1	1,763.9 ± 93.4
'Valencia'	17.9 ± 5.0	46.1 ± 13.7	58.4 ± 21.6	58.9 ± 5.8	45.6 ± 14.2	48.5 ± 14.3	101.2 ± 15.0	82.2 ± 54.8	119.9 ± 64.1	1,979.7 ± 51.7
'Valencia V1'	5.9 ± 6.1	54.4 ± 25.4	66.7 ± 24.2	62.4 ± 8.1	50.3 ± 15.4	42.5 ± 18.3	87.8 ± 6.4	82.2 ± 54.8	182.6 ± 74.5	1,965.6 ± 90.4
'SCS454 Catarina'	35.9 ± 20.5	65.7 ± 16.7	35.6 ± 11.6	53.3 ± 18.3	50.0 ± 11.3	43.8 ± 17.5	90.9 ± 9.7	105.7 ± 23.5	105.7 ± 37.4	1,879.3 ± 42.7
'Newhall'	43.0 ± 20.6	50.7 ± 26.7	56.1 ± 11.6	62.9 ± 4.9	29.4 ± 15.3	39.9 ± 20.0	176.3 ± 52.6	0.0 ± 0.0	162.7 ± 75.5	1,761.7 ± 55.2
'Folha Murcha'	36.1 ± 20.4	65.1 ± 21.5	32.9 ± 7.7	42.4 ± 14.3	37.3 ± 20.0	61.6 ± 13.6	97.1 ± 12.3	82.2 ± 54.8	187.6 ± 77.8	1,976.9 ± 98.5
'Bahia'	27.5 ± 21.1	26.8 ± 12.2	27.3 ± 25.1	66.8 ± 36.2	41.7 ± 32.0	54.3 ± 20.0	87.6 ± 30.1	42.5 ± 36.4	105.1 ± 66.1	1,905.3 ± 69.3
'Seleta Franck'	34.0 ± 21.8	31.4 ± 39.6	48.1 ± 20.6	56.6 ± 23.0	42.4 ± 20.6	38.1 ± 19.2	48.9 ± 19.3	154.3 ± 56.1	162.7 ± 75.5	1,721.1 ± 13.5
'Campo Alto'	24.6 ± 15.0	54.1 ± 20.4	44.4 ± 20.7	52.9 ± 17.2	46.7 ± 13.5	47.9 ± 14.6	89.7 ± 16.5	89.6 ± 59.8	187.6 ± 77.8	1,847.1 ± 97.5
'Natal'	24.5 ± 14.4	49.3 ± 17.0	50.6 ± 17.8	66.9 ± 17.3	48.4 ± 12.1	46.2 ± 18.3	89.3 ± 17.0	75.9 ± 50.6	145.8 ± 66.2	2,002.9 ± 84.0
'Navelina'	29.4 ± 14.9	29.3 ± 26.7	60.0 ± 16.2	60.2 ± 24.3	55.9 ± 18.4	41.9 ± 22.4	123.5 ± 38.8	41.4 ± 49.7	225.7 ± 61.1	1,604.0 ± 63.1
'Liberato Salzano'	37.6 ± 19.4	48.2 ± 38.6	55.7 ± 22.5	42.8 ± 16.6	57.1 ± 21.9	39.6 ± 20.2	87.8 ± 6.4	105.7 ± 23.5	204.4 ± 108.6	1,777.9 ± 116.7
'Hactur'	32.9 ± 22.5	47.9 ± 28.6	45.0 ± 14.9	42.3 ± 21.2	49.1 ± 6.7	34.7 ± 14.8	102.4 ± 31.5	59.7 ± 39.8	274.4 ± 79.8	1,845.0 ± 150.0
'Midknight'	59.4 ± 56.0	44.8 ± 7.4	37.0 ± 9.0	59.4 ± 10.1	56.2 ± 18.9	39.3 ± 20.4	71.8 ± 4.6	105.9 ± 70.6	234.4 ± 27.7	1,898.6 ± 19.3
'Valencia V5'	34.1 ± 22.8	52.1 ± 25.8	34.4 ± 9.6	52.0 ± 20.0	53.1 ± 19.0	41.5 ± 10.3	97.1 ± 12.3	82.2 ± 54.8	258.1 ± 28.0	1,890.3 ± 8.2
'Lima Sorocaba'	32.9 ± 16.7	58.1 ± 22.0	48.9 ± 24.6	35.2 ± 13.9	58.6 ± 18.7	43.6 ± 17.5	80.5 ± 26.4	78.6 ± 34.8	143.9 ± 31.6	1,875.6 ± 54.4
'Salustiana'	18.9 ± 12.6	44.7 ± 17.2	33.5 ± 15.3	58.3 ± 18.6	65.8 ± 21.8	46.4 ± 16.7	97.1 ± 26.6	87.0 ± 17.9	108.3 ± 37.4	1,834.2 ± 104.1
'Sanguinea'	40.1 ± 23.1	54.4 ± 22.2	38.2 ± 10.7	55.2 ± 17.3	60.0 ± 17.8	41.0 ± 16.2	73.5 ± 18.2	105.7 ± 23.5	122.3 ± 45.3	1,884.2 ± 52.6
'Valencia Late'	35.6 ± 20.7	49.2 ± 27.7	56.1 ± 11.6	44.2 ± 19.9	56.3 ± 12.3	32.7 ± 12.4	79.8 ± 14.2	95.4 ± 63.6	104.8 ± 74.2	2,060.5 ± 71.4
'Lue Gim Gong'	27.8 ± 22.8	67.0 ± 21.9	26.1 ± 5.9	50.9 ± 17.4	53.9 ± 14.7	51.7 ± 13.7	86.5 ± 18.0	71.7 ± 53.8	174.3 ± 82.2	1,865.4 ± 59.4
'Jaffa'	32.0 ± 2.5	46.6 ± 20.3	44.0 ± 25.8	76.4 ± 2.3	51.0 ± 7.1	39.4 ± 17.5	64.2 ± 6.0	0.0 ± 0.0	427.4 ± 35.7	1,730.5 ± 49.8

[1] BBCH 51 – Swollen buds, scales are visible and slightly green; BBCH 53 – Buds burst, and floral primordia are visible; BBCH 55 – Flowers become visible and are closed. BBCH 56 – Petals grow and sepals surround half the corolla; BBCH 59 – Flowers still closed, with petals forming a hollow and elongated ball; BBCH 65 – Full bloom (50% of the flowers are open); BBCH 69 – End of flowering, missing (fallen) petals and the stylus remains; BBCH 72 – Green fruit surrounded by sepals and without the stylus; BBCH 73 – Some fruits turn yellow: Beginning of the physiological fruit drop; BBCH 74 – Fruit reaches 40% of the final size, dark green color and end of the physiological drop; BBCH 81 – Beginning of fruit color change.

Table 3. Accumulated degree-days (ADD, °C) and mean day interval (MDI) between the phenological stages 51 - 81, 51 - 65 and 65 - 81 of the BBCH scale[1], in orange trees of the Citrus Collection of the Experimental Agronomic Station - UFRGS, in the 2015-16, 2016-17 and 2017-18 growing seasons. Eldorado do Sul, RS, Brazil[2].

Cultivars	ADD 51 - 81	MDI 51 - 81	ADD 51 - 65	MDI 51 - 65	ADD 65 - 81	MDI 65 - 81
'Rubi'	2,380.2 B	274 B	218.5	49	2,161.7 B	226 B
'Cabula'	2,420.5 B	276 B	210.8	46	2,209.7 B	230 B
'Piralima'	2,406.0 B	275 B	240.8	51	2,165.2 B	224 B
'Lima Verde'	2,408.6 B	275 B	213.1	47	2,195.5 B	228 B
'Hamlin'	2,347.1 B	268 B	229.5	48	2,117.6 B	220 B
'Valencia'	2,558.5 A	296 A	227.0	48	2,331.5 A	248 A
'Valencia V1'	2,600.5 A	311 A	239.8	52	2,360.7 A	259 A
'SCS454 Catarina'	2,466.0 B	281 B	240.5	50	2,225.5 B	231 B
'Newhall'	2,382.6 B	270 B	242.1	50	2,140.5 B	221 B
'Folha Murcha'	2,619.4 A	315 A	213.9	45	2,405.4 A	270 A
'Bahia'	2,460.3 B	280 B	217.3	46	2,243.1 B	235 B
'Seleta Franck'	2,337.7 B	266 B(-)	212.5	45	2,125.2 B	221 B
'Campo Alto'	2,484.6 B	284 B	222.6	47	2,262.0 B	237 B
'Natal'	2,599.7 A	308 A	239.7	49	2,360.0 A	259 A
'Navelina'	2,306.4 B	262 B(-)	242.5	50	2,063.9 B(-)	212 B(-)
'Liberato Salzano'	2,456.8 B	289 B	241.3	49	2,215.5 B	240 B
'Hactur'	2,533.4 A	300 A	217.2	49	2,316.2 A	251 A
'Midknight'	2,606.9 A	309 A	256.8	53	2,350.0 A	256 A
'Valencia V5'	2,594.9 A	307 A	225.8	46	2,369.2 A	261 A
'Lima Sorocaba'	2,455.9 B	278 B	233.7	48	2,222.3 B	230 B
'Salustiana'	2,394.1 B	274 B	221.1	52	2,173.0 B	223 B
'Sanguinea'	2,474.6 B	284 B	247.9	50	2,226.8 B	234 B
'Valencia Late'	2,614.7 A	310 A	241.5	49	2,373.2 A	261 A
'Lue Gim Gong'	2,488.0 B	283 B	231.8	47	2,256.2 B	236 B
'Jaffa'	2,511.5 A	291 B	250.1	48	2,261.5 B	243 A
p	0,0088	<0,0001	0,9924	0,9998	0,0002	<0,0001
CV (%)	4,45	4,04	16,51	15,72	3,98	5,90

[1] BBCH 51 – Swollen buds, scales are visible and slightly green; BBCH 65 – Full bloom (50% of the flowers are open); BBCH 81 – Beginning of fruit color change.

[2] Means followed by the same letters form groups by the Scott-Knott test ($p<0.05$); (-) significant difference downwards, in relation to the standard cultivar 'Valencia', by Dunnett's test ($p<0.05$).

Floral induction in citrus plants occurs about 3 to 5 months before flowering itself. Low temperatures and water stress are the main promoters of floral induction (GRAVINA, 2014). Ramos-Hurtado et al. (2006) indicated that floral induction should occur in July for the 'Montenegrina' mandarin tree grown under the same edaphoclimatic conditions as the ones in Rio Grande do Sul. Afterwards, for this cultivar in similar edaphoclimatic conditions, there was flowering inhibition due to the gibberellic acid application in June (GRIEBELER et al., 2021).

Micheloud et al. (2018), studying the phenology of several citrus cultivars, in an area where floral induction and the beginning of sprouting are also determined by low temperatures. The combination of both solar radiation and the temperature of the month of July affected the starting period of spring sprouting. In this study, which was carried out in temperate conditions, the first phenological stage observed was the green bud (BBCH 55), which occurred in mid-August.

Under the conditions of the Depressão Central, there are on average 5 to 10 days of frost in the year, some of that occurring late in the spring (SARTORI, 2003). There

were moderate occurrences of the phenomenon, after the beginning of sprouting, on September 12 and 13, 2015, (minimum temperatures of 2.7 and 2.4 °C, respectively), which did not compromise the sprouts because they were more developed and because anthesis had already occurred.

Table 4. Mean dates interval between 81 stage and harvest (MDI 81-H), Mean date of fruit harvest (H) at horticultural maturation of orange trees from the Citrus Collection of the Experimental Agronomic Station - UFRGS, in the 2016, 2017 and 2018 growing seasons, and recommended harvest period. Eldorado do Sul, RS, Brazil[1]

Cultivars	MDI 81 - H	H	Harvest period
'Rubi'	41 B(-)	05/22[2] ± 08	May to October(A); June to September(B)
'Cabula'	37 B(-)	05/20 ± 08	-
'Piralima'	36 B(-)	05/21 ± 10	March to June(D)
'Lima Verde'	75 B	06/28 ± 53	June to September(D)
'Hamlin'	42 B(-)	05/21 ± 10	April to October(A); May to July(B)(D)
'Valencia'	134 A	09/18 ± 19	September to January(A); August to December(D)
'Valencia V1'	120 A	09/18 ± 19	-
'SCS454 Catarina'	28 B(-)	05/21 ± 10	April to July(B); April to June(D)
'Newhall'	40 B(-)	05/22 ± 08	April to May(C); April to June(B)(D)
'Folha Murcha'	120 A	09/21 ± 20	September to February(A); October to February(B)(D)
'Bahia'	62 B(-)	06/23 ± 35	May to July(B); May(C); June to August(D)
'Seleta Franck'	44 B(-)	05/22 ± 08	May to August(D)
'Campo Alto'	50 B(-)	06/16 ± 26	-
'Natal'	136 A	10/04 ± 13	October to December(D)
'Navelina'	45 B(-)	05/21 ± 10	April to May(C); April to June(B)(D)
'Liberato Salzano'	45 B(-)	06/06 ± 14	-
'Hactur'	127 A	09/18 ± 19	-
'Midknight'	120 A	09/19 ± 28	August to September(C); July to October(E)
'Valencia V5'	120 A	09/18 ± 19	-
'Lima Sorocaba'	39 B(-)	05/31 ± 18	April to July(B)
'Salustiana'	38 B(-)	05/27 ± 11	May to June(C); May to July(B)
'Sanguinea'	42 B(-)	06/10 ± 30	April to July(B)
'Valencia Late'	112 A	09/09 ± 30	September(C); August to November(E)
'Lue Gim Gong'	133 A	08/30 ± 43	August to November(D)
'Jaffa'	0 B(-)	05/22 ± 11	May to July(F); July to September(B)
p	<0,0001		
CV (%)	40,38		

[1]Means followed by the same letters form groups by the Scott-Knott test (p<0.05); (-) significant difference downwards, in relation to the standard cultivar 'Valencia', by Dunnett's test (p<0.05).
[2] Month/Day.
(A) Sartori et al. (2002); (B) Koller and Soprano (2013); (C) Micheloud et al. (2018); (D) Schwarz et al. (2018); (E) Oliveira et al. (2008a); (F) Oliveira et al. (2008b); -, no information.

Frost happened again from 17 to 21 July 2017 (consecutive minimum temperatures of 1.51, -1.52, -2.93, -1.21 and 1.41 °C) and, because it was more intense and having occurred at an early stage of development of the sprouts, it caused damage that compromised the integrity of the sprouted structures and induced a subsequent formation of a new sprout, in early August. This fact was also observed by Rivadeneira et al. (2006) and corroborates with Gravina (2014) states: the younger the sprouted plant tissue, the greater its susceptibility to damage caused by the cold.

The damage caused in orange trees by the frost that occurred in July may not directly affect fruit production, as verified in the

Santa Fé region, Argentina, where the event reduced the number of flowers in the next sprouting (immediately after the frost), however there were no changes in yield when compared to years without frost damage, since there was compensation due to the higher fruit fixation rate of these few flowers (MICHELOUD et al., 2016).

The frost is the most pivotal meteorological element in subtropical and temperate citrus production (RIVADENEIRA, 2012). Despite this, the study region was deemed suitable for all cultivars, with restrictions only to rootstocks that are less resistant to cold, because of the citrus agroclimatic zoning in Rio Grande do Sul. This is due to the lower probability of frost occurring when compared to other locations with thermal insufficiency (<1,800 ADD) and high risk of frost (>50%) in the year (WREGE et al., 2004).

Full bloom (BBCH 65) occurred between August 28 and September 22, depending on each cultivar. For the 'Cabula', 'Rubi', 'Lima Verde' and 'Folha Murcha' orange trees this phenological stage was reached in the month of August and they were the first to bloom. The 'Sanguinea', 'Salustiana', 'Midknight' and 'Jaffa' orange trees fully blossomed after mid-September.

In a five-year study by Micheloud et al. (2018) in temperate conditions, in the central region of Santa Fé, Argentina, the opening of 50% of the flowers occurred seven days later for the cultivars 'Newhall', 'Navelina' and 22, 25, 15 and 20 days later for 'Bahia', 'Valencia Late', 'Midknight', and 'Salustiana', respectively, when compared to the same cultivars in this work.

Among the phenological stages studied, at the beginning of the reproductive cycle of orange trees, the ADD values between one stage and another are lower (Table 2). This is due to the milder temperatures of late winter and early spring when they occur and also because of the greater detail in the development of the structures, subdividing the beginning of the cycle into more phases. The longest sub period occurred between the fruit stages in which the fruits had 40% of their final size (BBCH 74) until their color change (BBCH 81).

There was a statistical difference for the MDI and ADD intervals of the phenological stages BBCH 51 - BBCH 81 and BBCH 65 - BBCH 81. In both cases, the cultivars were divided in two groups. From the perspective of the entire evaluation period (BBCH 51 - BBCH81), in the group of cultivars with the earliest reproductive cycle, the MDI ranged from 262 to 291 and 2,306.4 to 2488.0 ADD, whereas in the latter group the MDI ranged from 296 to 315, accumulating from 2,511.5 to 2,619.4 degree-day (Table 3).

Between the BBCH 51 and BBCH 65 stages, there were no statistical differences both for the MDI, which varied between 45 and 53 days, depending on the cultivars, and for the thermal accumulation which varied between 210.8 and 256.8 ADD. These values were higher than those found by Sharma et al. (2017) in the semi-arid conditions of the Indian state of Haryana, for the 'Jaffa' (104.9 ADD) and 'Pineapple' (145.5 ADD) orange trees, and those found by Nascimento et al. (2018), also in semi-arid conditions of the Submédio São Francisco (Petrolina, PE, Brazil), for the 'Pera-D12' (11.65 days / 181.32 ADD, when grafted on the Rangpur lime and 12.42 days / 188.82 ADD on the Volkamer lemon) and 'Rubi' orange trees (11.99 days / 187.85 ADD, when grafted on the Rangpur lime and 11.23 days / 168.93 ADD on the Volkamer lemon), considering the same subperiods of the phenological stages. Despite being one of the last to sprout and bloom, the 'Jaffa' orange tree was one of the first to present the beginning of the physiological fruit drop, BBCH stage 73, together with the 'Rubi', 'Lima Verde' and 'Bahia' orange trees.

The last stage evaluated in this work, BBCH 81 - beginning of the skin color change, was reached first by the 'Navelina', 'Seleta Franck' and 'Hamlin' orange trees, in the first ten days of April. The first two cultivars were more precocious in relation to 'Valencia', the most cultivated orange tree in the State, in terms of the average interval between days BBCH 51, bud swelling, and BBCH 81. 'Navelina' was even more precocious than the reference cultivar, when considering the interval between stage BBCH 65 to BBCH 81, with an MDI of 212 and 2,063.9 ADD, in that period.

The beginning of phase III of fruit development, skin color change (BBCH stage 81), under the conditions of the Depressão Central, occurred after what was observed in a study carried out in Argentine temperate climate environment (MICHELOUD et al., 2018), comparing the 'Newhall', 'Navelina', 'Bahia', 'Valencia Late', 'Midknight', and 'Salustiana', orange trees, common to both studies. This fact may be linked to the greater thermal amplitudes observed in environments of greater continentality (HASLER et al., 2015). This shows that the same genotypes alter their development cycle because of the environmental characteristics to which they are submitted.

The later cultivars, regarding skin color change, were the 'Valencia' (all their derivations), 'Natal', 'Midknight' and 'Folha Murcha' orange trees, with the change occurring in the second half of May. 'Jaffa' was also classified as a long-cycle cultivar, through ADD analysis, however as for MDI, it is among the short-cycle cultivars. This happened because it started its spring sprouting late, in August, decreasing the cycle time. The cultivar 'Hactur' can also be considered a late orange tree because it started changing the color of skin on May 13, the average date in the three years evaluated.

Stenzel et al. (2006) confirm that the 'Folha Murcha' orange tree shows late maturation, and in the conditions of Paraná, Brazil, the period between anthesis (BBCH 65) and fruit maturation (BBCH 83) varied from 4,462 to 5,090 ADD, depending on the rootstocks tested, in the Northwest and North of that State. In turn, Rivadeneira (2012) with 'Newhall', 'Valencia Late' and 'Salustiana' orange trees grafted on *Poncirus trifoliata* in the province of Entre Ríos, Argentina, obtained between 2,153.3 and 2,526.4 ADD, from anthesis (BBCH 65) to fruit maturation (BBCH 83), considering the lower basal temperature of 12.5 °C. In the present study, the same cultivars presented between 2,140.5 to 2,373.2 ADD from the anthesis (BBCH 65) until the change in the skin color of the fruits (BBCH 81), under the conditions of the Depressão Central of Rio Grande do Sul.

The differences between the cultivars under study for the interval of days between stage 81 and harvest (MDI 81-H) are presented in Table 4. Corroborating with the results described above, there are formation of two groups, the earlier group (0 day ≤ MDI 81-H ≤ 75 days), consisting of 'Rubi', 'Cabula', 'Piralima', 'Lima Verde', 'Hamlin', 'SCS454 Catarina', 'Newhall', 'Bahia', 'Seleta Franck ', 'Campo Alto', 'Navelina', 'Liberato Salzano', 'Lima Sorocaba', 'Salustiana', 'Sanguinea' and 'Jaffa'; and the late group (112 days ≤ MDI 81-H ≤ 136 days), formed by 'Valencia', 'Valencia V1', 'Folha Murcha', 'Natal, 'Hactur', 'Midknight', 'Valencia V5', 'Valencia Late' and 'Lue Gim Gong'. Furthermore, within the earlier maturation group, when compared to 'Valencia' (considered the standard cultivar in southern Brazil), 'Lima Verde' was the only cultivar that did not differ from 'Valencia'. The cultivars had the same grouping when comparing MDI 81-H (Table 4) with the variables ADD and MDI at different intervals of phenological stages (Table 3), except for 'Lue Gim Gong' and 'Jaffa'.

The harvest period for the region recommended by the literature is compiled in for those cultivars for which information is available (Table 4). The harvest date has a greater or lesser standard deviation depending

on the cultivar over the growing seasons. All cultivars were harvested within the period indicated for the region (SARTORI et al., 2002; OLIVEIRA et al., 2008a, 2008b; KOLLER; SOPRANO, 2013; MICHELOUD et al., 2018; SCHWARZ et al., 2018).

The late group of cultivars in relation to MDI 81-H (112 days ≤ MDI 81-H ≤ 136 days) (table 4) showed a large uncoupling between external (peel) and internal (pulp) fruits maturation. Also, it had an earlier external fruit maturation than the internal maturation necessary for harvesting. This behavior is observed in several citrus species (JULHIA et al., 2019; SINGH et al., 2023). Varieties with this behavior should not be harvested based on external color even in subtropical conditions (SINGH et al., 2023).

The weather conditions observed were different for the three growing seasons evaluated. The accumulated annual precipitation reached the volumes of 2,089, 1,758 and 1,250 mm in the 2015-16, 2016-17 and 2017-18 growing seasons, respectively. The annual temperature means were very similar, being 18.7, 18.8 and 18.9 ºC, respectively. However, the monthly means of minimum temperatures in the coldest months (May, June, and July) were 10.2, 7.0 and 9.7 ºC, in the three growing seasons, respectively (Figure 2).

Variations in the behavior of the weather between years are common in the conditions of southern Brazil, which requires greater attention in the management of agricultural crops in this region (SARTORI, 2003). Environmental conditions also influenced the occurrence of phenological phases in the 'Tahiti' acid lime, in the west of Paraná (VILLA et al., 2017).

Low temperatures, in subtropical and temperate zones, promote citrus flowering (GRAVINA, 2014). Such condition, followed by a period of maximum daytime temperatures above 26.6 °C and maximum nighttime above 21.1 °C for more than seven consecutive days (ALBRIGO et al., 2002), trigger the visible process of citrus development: the sprouting.

All cultivars developed completely, from the beginning of sprouting to maturation, since the environmental conditions of the study site are in accordance with the accumulation of degree-days required by the orange trees evaluated (WREGE et al., 2004). Through the standard deviation values of the results, in Tables 1 and 2, differences between the dates and the accumulation of degree-days for the same phenological stages between the years evaluated can be seen. This interannual variation was verified in several studies of this nature (RIVADENEIRA, 2012; SHARMA et al., 2017; MICHELOUD et al., 2018).

Conclusions

The orange trees cultivated in the Depressão Central of Rio Grande do Sul - Brazil started to sprout between the mean dates of July 11 to August 5, depending on cultivar. The full bloom of orange trees in this region occurred between the mean dates of August 28 and September 22.

The orange genotypes studied in this work were subdivided into two groups, according to the accumulation of degree days and the average interval of days between the phenological stages BBCH 65 to BBCH 81 and BBCH 51 to BBCH 81. The group of precocious cultivars consists of: 'Bahia', 'Cabula', 'Campo Alto', 'Hamlin', 'Liberato Salzano', 'Lima Verde', 'Newhall', 'Piralima', 'Rubi', 'SCS454 Catarina', 'Seleta Frank', 'Lima Sorocaba', 'Lue Gim Gong', 'Navelina', 'Salustiana' and 'Sanguinea'; and the group of late cultivars by: 'Folha Murcha', 'Hactur', 'Midknight', 'Natal', 'Valencia', 'Valencia Late', 'Valencia V1' and 'Valencia V5'. The orange tree 'Jaffa' was classified as precocious as for ADD and as late for MDI.

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