Comparison of chilling units and hours for apple production in Brazil and in Japan

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Abstract

The Brazilian apple production are located in the southern region, with the best areas in altitudes ranging from 800 to 1400 m, with great variability in the number of Chilling Hours equal or below 7.2°C and Chilling Units in the different regions and years. The objective of this study was to compare Chilling Hours equal or below 7.2°C and Chilling Units by the North Carolina Modified model in different regions of southern Brazil, with Aomori region in Japan. In Brazil was used historical data of the CH and CU from 2000 to 2016 in the municipalities of Caçador (960 m), Videira (774 m), São Joaquim (1376 m), Fraiburgo (1038 m) and Vacaria (986 m). In Aomori (2.8 m) the historical data used was from 2000 to 2015. The results shows that in southern Brazil there is a variation in the number of CH among sites and years, being greater in the sites of higher altitude, with an average of 880 CH in São Joaquim and 411 CH in Videira. When compared the Brazilian regions with Aomori, the Japanese region have a greater CH accumulation. Once CU have the same behavior of CH in respect to altitudes, but shows a larger variability between years in the different regions of southern Brazil, is possible to affirm that the North Carolina Modified method is more accurate to quantify the chilling in regions with large temperature fluctuations in the autumn and winter, while for regions with low thermal amplitude, the model of CH presents a better adherence.

Keywords: Climate Change. Temperate Fruit Crops. Winter Cold.

Resumo
Comparação das Unidades de Frio e Horas de frio para a macieira na região Sul do Brasil e em Aomori no Japão

As regiões produtoras de maçã se localizam na região Sul do Brasil, tendo como destaque regiões com atitudes de 800 a 1400 m, havendo grande variabilidade no número de Horas de Frio ≤ 7,2^{o}C e Unidades de Frio entre as diferentes regiões e anos estudados. O objetivo deste trabalho foi comparar as Horas de Frio ≤ 7,2^{o}C e Unidades de Frio pelo método Carolina do Norte Modificado em diferentes regiões do Sul do Brasil, comparando com a região de Aomori no Japão. No Brasil, foram utilizados dados históricos de UF e HF de 2000 a 2016, entre os meses de maio e setembro nos municípios de Caçador (960 m), Videira (774 m), São Joaquim (1376 m), Fraiburgo (1038 m) e Vacaria (986 m). Em Aomori (2,8 m) foram utilizados dados históricos no período de 2000 a 2015. Os resultados mostram que no Sul do Brasil há uma variação do número de HF entre locais e anos, sendo maior nos locais de maior altitude, variando na média de 880 a 411 em São Joaquim e Videira, respectivamente. Verificou-se maior acúmulo de HF em Aomori, em relação ao Sul do Brasil. As UF teve o mesmo comportamento em relação às altitudes, apresentando maior variabilidade entre os anos nas diferentes regiões do Sul do Brasil, permitindo afirmar que o método de UF é mais preciso para quantificar o frio na dormência em regiões com grandes flutuações de temperatura no outono e inverno, enquanto que para regiões com menor amplitude térmica o modelo de HF apresentando melhor aderência.

Palavras-chave: Mudanças Climáticas. Frutas de Clima Temperado. Frio de inverno.

Introduction

The apple trees needs to go through a period with low temperatures to get out of the dormancy. It is characterized by the fall of the leaves at the end of the cycle and, consequently, fall into winter dormancy, with drastic reduction of their metabolic activities. According to Petri *et al*. (2006) in these regions where winter is mild or even subtropical, where chill is insufficient to satisfy the physiological needs of dormancy, numerous anomalies occur, such as sprouting and delayed flowering, which reduce productivity and fruit quality. Putti *et al*. (2002) determined the chilling requirement of six apple cultivars, using the technique of isolated node cuttings and cuttings with multiple buds. These authors observed that in most cultivars, there was an increase in the number of days to budding 1060 and 1560 CU, compared to 530 CU of North Caroline Model. Francescatto *et al*. (2016) mentions that the climatic conditions are important factors in determining the quality of the flower and, consequently, this affects the potential for fertilization and productivity of fruits. In addition, regions where winter is mild or irregular, several physiological anomalies occur in the plant, thus compromising the productive potential of apple trees. In Brazil, the apple production is located in the South region, with emphasis on regions with attitudes ranging from 800 to 1400 m above sea level, with a great variability in the number of chilling hours (CH) and chill units (CU) between the different regions and years studied. The CH method has been used to quantify the chill requirement in temperate fruit trees during the winter period. This method was developed by Weinberger (1950), where only the CH number is counted below 7.2^{o}C during the rest period of the peach tree. The CH model below 7,2^{o}C expresses the chill intensity to satisfy the chill requirements of the temperate fruit trees in regions of constant winter, but where there are variations of temperature not expressed the needs of the plant. Given the difficulties of quantifying the chill requirements in mild winter regions, by the CH method below 7.2^{o}C, several models were developed that assign different values to temperature ranges with temperatures below 7,2^{o}C are also considered effective. Among the most studied models we can mention the weighted model, the Unrath model (SHALTOUT; UNRATH, 1983), the North Carolina model, among others, which consider temperature ranges. Erez; Lavee (1971 and Richardson *et al*. (1974) report that the model of Utah obtained satisfactory performance in the United States in the regions of Utah and Carolina do Norte, respectively. Thus Hawerroth, (2009) mentions that these models basically consist conversion of hourly temperatures to CH, and the units are accumulated daily until reaching a total that theoretically corresponds to the end of the dormancy phase of a given cultivar. In this way the CH can be calculated covering a wide range of temperatures during the winter period.

The models proposed by Erez; Lavee (1971); Richardson *et al*.(1974); Shaltout; Unrath (1983) were developed under regular winter conditions to Northern Hemisphere. Considering regions with mild climate and with irregular winters Petri (2006), report that is frequent the interruption of the winter by high temperatures that results in a negative effect on the accumulated chill, for this reason the North Carolina model was modified for the conditions of the Plateau Catarinense, described by Braga *et al*. (1987) apud Thomazi (2011). According to Petri (2006), it was proposed to restrict the number of days with positive CU, which can be influenced by high temperatures, after 96 hours of the last accumulation of CH with high temperatures, avoiding that in certain situations it would reach the end of dormancy with the negative accumulation of CU. Also according to the author, the models were correlated with the budbreaking of apple trees in three sites for five years. Therefore, the objective of this paper was to compare CH equal to or below 7.2^{o}C and CU North Carolina Modified model in the different regions of Southern Brazil, where the largest apple producing regions are concentrated and comparing with the Aomori region in Japan also known as Japan's largest apple producer.

Material and Methods

We used historical data between 2000 and 2016 of Chill Units (CU) and Chill Hours equal to or lower than 7.2^{o}C in five regions of southern Brazil, with different altitudes. These main regions and their geographic coordinates of the meteorological stations are presented in Table 1.

Based on the temperature data obtained from the main apple producing regions in the southern region of Brazil, the CH values were equal to or below 7.2^{o}C, considering a linear variation of temperature between the hours of the maximum, minimum and 21h daily temperatures. For the calculation of CH, agrometeorological system SISAGRO 2 (PEREIRA *et al*., 2004) was used. This methodology of estimation of CH is based on the interpolation of the values of the observed temperatures in four daily schedules described by Pereira *et al*. (2004). In order to estimate the chilling hours in the Aomori region, daytime temperatures of below or equal to 7.2^{o}C were used during the months of October to February during 2000 to 2016 year. In this case the calculation was done using the Microsoft Excel 2010 program.

To calculate the chill units (CU) we used the modified North Carolina, described by Braga *et al*. (1987). The calculation of CU was also performed on the platform of the agrometeorological system SISAGRO 2 (PEREIRA *et al*., 2004). For this, the same data were used to calculate the CH to calculate the CU of the southern region of Brazil and the region of Aomori / Japan during the winter. The winter in Japan comprises the months of October to February and in Brazil the winter comprises the months of May to September.

Statistical analysis of the data was performed using the Microsoft Excel 2010 program where the standard deviation and the coefficient of variation of CH and CU were calculated.

Table 1. Altitude and geographic coordinates of the main producing areas of apple in southern Brazil and Aomori region in Japan.

Location	Altitude (m)	Longitude (E-W)	Latitude (N-S)
Caçador	945	26° 49’ 09’’	50° 59’ 08’’
Videira	774	27° 01’ 29’’	51° 08’ 58’’
São Joaquim	1376	28° 17’ 59’’	49° 56’ 01’’
Fraiburgo	1038	27° 04’ 50’’	50° 54’ 17’’
Vacaria	951	28° 30’ 49’’	50° 52’ 57’’
Aomori/Japan	2,8	40° 49’ 03’’	140° 46’ 01’’

Results and Discussion

In the Southern region of Brazil there was a great variability in chilling hours (CH) equal to or below than 7.2°C between sites and years, with higher variability in the higher altitude sites, ranging from 880.2 to 410.8m in average São Joaquim and Videira, respectively (Figure 1 and Table 2).

Variability between years is observed at all locations, regardless of altitude. In São Joaquim, higher altitude region, the lowest CH accumulation occurred in 2015, with 583 CH and the highest with 1168 CH in 2016, representing a variation of 100.3%. This indicates the need for annual monitoring of CH in different regions to identify the level of dormancy. These results show that there is a deficit of CH to complete dormancy of apple trees in regions altitude above 1000 m, manifesting symptoms of lack of chill with greater or lesser intensity according to the years. Already in Aomori the number of CH was much superior to all regions of Southern Brazil, which shows a constant winter, which can meet the requirements in chill to the apple tree, although it is observed variability between years, with the exception of 2000 a 2004 (Figure 1). This high accumulation of CH in Aomori is due to the average temperature of 3.5^{o}C in the period from October to February. These results are similar to results obtained by Petri *et al*. (1996). These authors observed the same variation of CH in southern Brazil: São Joaquim, Caçador and Videira during the period from 1980 to 1984. Already Morais; Carbonieiri (2015) also observed a great variability of CH in the Palmas region, in Brazil. Besides the altitude and the region influence the variability of CH accumulation, the year factor that can influence this variability.

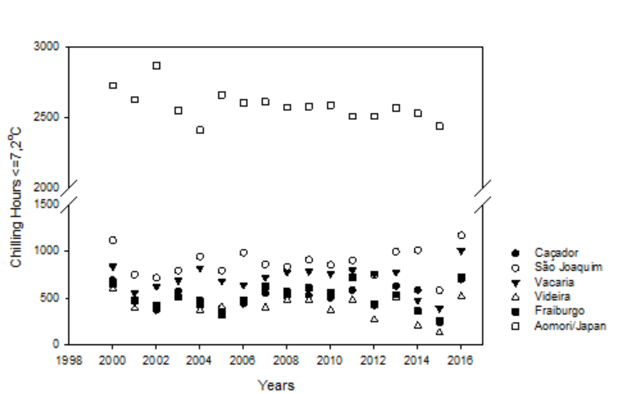

Figure 1 - Chilling hours accumulation, during the 16 years evaluated in different regions producing apples from Brazil and Japan.

Table 2 - Chilling hours ≤7.2°C accumulated in different regions average of 16 years evaluated in different regions producing apples from Brazil and Japan.

Region	Month	Average	SD*	CV** (%)
	May	95.2	54.2	57.0
	June	203.4	84.7	41.6
Caçador	July	348.1	112.2	32.2
	August	436.5	129.0	29.5
	September	505.8	120.5	23.8
	May	96.9	48.6	50.2
	June	213.6	88.0	41.2
Fraiburgo	July	368.5	109.5	29.7
	August	464.3	131.9	28.4
	September	513.1	131.8	25.7
São Joaquim	May	188.9	80.7	42.7
	June	363.1	123.0	33.9
	July	565.7	135.5	23.9
	August	722.4	151.2	20.9
	September	880.2	148.8	16.9

Vacaria	May	124.5	51.4	41.3
	June	278.6	96.9	34.8
	July	473.9	125.2	26.4
	August	615.1	137.9	22.4
	September	711.8	145.2	20.4
Videira	May	76.3	46.2	60.6
	June	165.9	67.4	40.6
	July	293.3	95.6	32.6
	August	368.7	111.1	30.1
	September	410.8	121.2	29.5
Aomori/Japan	October	70.2	33.3	47.4
	November	478.1	99.0	20.7
	December	1177.4	109.3	9.3
	January	1916.4	111.6	5.8
	February	2584.9	109.5	4.2

*SD – Standart Deviation; ** CV - Coefficient of Variation

In relation to the CU method Modified North Caroline, gave the same behavior relative altitudes in southern Brazil (Table 3). It is noteworthy that the CU São Joaquim was 429.1% higher than Videira, region of lower altitude. Fritzsons *et al.* (2008) mentions that the altitude is the factor that most influences on temperature, followed respectively by latitude and longitude. Morais; Carbonieiri (2015) also observed the same differences, where lower temperatures in the region of higher altitude accounted for the largest amount of chill units, while higher temperatures in the lower altitude locations provided less chill units or to units of negative temperatures in April and May. In addition, Fenili *et al.* (2016) observed that the months of May, June and July are the main contributors to the accumulation of chill units and August and September, present the greatest variations between years, with a small contribution. The largest accumulation of chill units was recorded in São Joaquim, the average during the 16 years evaluated totaled over 2139.9 CU by North Caroline Modified method (Table 3). Similar results were seen by Morais; Carbonieri (2015). In relation to CU in Aomori, did not present the same behavior of CH, being less than São Joaquim and Vacaria and very close to Caçador and Fraiburgo (Table 3). This can be attributed to the calculation model CU North Caroline where cancel or negative temperatures do not add to the accumulation of CU, as well as temperatures above 16^{o}C. In Aomori by the average temperatures of 3.5^{o}C estimated that occur long periods with negative temperatures. This demonstrates that different from southern Brazil, to Aomori model CU Modified North Caroline is not adequate to estimate the chill intensity of dormancy apple tree, being more suitable method CH at or above 7,2^{o}C.

There was a greater variability between the years in the different regions of Southern Brazil (Figure 2), which allows to affirm that the CU North Carolina Modified method is more accurate to quantify the chill for dormancy in regions with large temperature fluctuations in the autumn and winter, whereas for regions with lower thermal amplitude the CH model is more adequate.

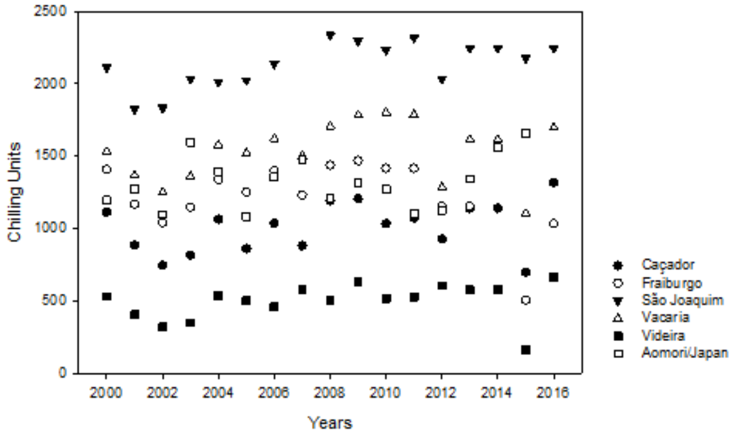

Figure 2 – Chilling Units accumulation using the Modified North Carolina method, during the 16 years evaluated in different regions producing apples from Brazil and Japan.

Table 3 – Chilling Units accumulation in different locations using the Modified North Carolina method. Average the 16 years evaluated in different regions producing apples from Brazil and Japan.

Region	Month	Average	SD*	CV** (%)
Caçador	May	274.4	97.6	35.6
	June	518.6	145.3	28.0
	July	776.4	137.5	17.7
	August	903.6	170.2	18.8
	September	1007.3	173.9	17.3
Fraiburgo	May	347.3	113.2	32.6
	June	628.2	184.2	29.3
	July	939.2	187.6	20.0
	August	1098.5	262.4	23.9
	September	1222.5	240.0	19.6
São Joaquim	May	622.6	116.6	18.7

	June	1044.2	151.3	14.5
	July	1474.2	157.2	10.7
	August	1791.5	163.0	9.1
	September	2130.9	160.2	7.5
Vacaria	May	396.1	115.2	29.1
	June	727.9	142.7	19.6
	July	1083.5	146.0	13.5
	August	1318.5	185.6	14.1
	September	1536.2	203.6	13.3
Videira	May	152.5	70.0	45.9
	June	295.1	112.5	38.1
	July	454.6	173.7	38.2
	August	470.2	170.7	36.3
	September	496.5	125.8	25.3
Aomori/Japan	October	338.5	53.2	15.7
	November	834.6	64.2	7.7
	December	1092.7	128.3	11.7
	January	1192.0	143.4	12.0
	February	1315.0	182.2	13.9

*SD – Standart Deviation; ** CV - Coefficient of Variation

Conclusions

It was observed that in the South region of Brazil there was a variation of the number of CH between regions, being related to altitude, where higher altitude regions have a higher accumulation of CH. When compared to Aomori / Japan, we found a higher accumulation of CH in relation to the South of Brazil. In relation to the years CH present a great variability, both in the South of Brazil and in Aomori.

We affirm that the North Caroline Modified Model CU method is more precise to quantify the chill for the dormancy in regions with temperature fluctuations in autumn and winter, and for CH chill regions the CH model is more adequate.

Reference

BRAGA, H. J.; SILVA, L. M. K. da. Sistema Agrometereológico para Microcomputador. In: CONGRESSO BRASILEIRO DE AGROMETEREOROLOGIA; 4; Belém-Pará, **Anais,** v.1, p380-385, 1987.

EBERT, A. et al. First experiences with chill units models is southern Brazil. **Acta Horticulturae**, n.184, p. 89-96, 1986.

EREZ, A.; LAVEE, S. The effect of climatic condition development of peach buds: temperature. **Journal of the American Society for Horticultural Science**, v. 96, n. 6, p. 711-714, 1971.

FRANCESCATTO P. et al. Quality of apple flowers grown in different latitude. In: XXIX IHC – PROC. INT. SYMPOSIA ON THE PHYSIOLOGY OF PERENNIAL FRUIT CROPS AND PRODUCTION SYSTEMS AND MECHANISATION, PRECISION HORTICULTURE AND ROBOTICS. **Acta Hortic,** p. 95 – 102, 2016.

FRITZSONS, E.; MANTOVANI L. E.; AGUIAR A. V. de. Relação entre altitude e temperatura: uma contribuição ao zoneamento climático no estado do Paraná. REA - **Revista de Estudos Ambientais**, v.10, n. 1, p. 49-64, 2008.

HAWERROTH, F. J. **Dormência de gemas sob influência da temperatura durante o período hibernal e resposta produtiva da macieira pelo uso de indutores de brotação.** 2009. 123 f. Dissertação (Mestrado) – Programa de Pós-Graduação em Agronomia - Fruticultura de Clima Temperado. Faculdade de Agronomia Eliseu Maciel. Universidade Federal de Pelotas, 2009.

HELDWEIN, A. B. et al. Disponibilidade de horas de frio na região central do Rio Grande do Sul: 1 – ocorrência de valores acumulados para diferentes níveis de probabilidade. **Cienc. Rural**, v.30, n.5, 2000.

MORAIS, H.; CARBONIERI, J. Horas e unidades de frio em pomares de maçã com diferentes microclimas. **Rev. Bras. Frutic.**, v. 37, n. 1, p. 001-012, 2015.

PEREIRA, E. S.; BRAGA, H.J.; SILVA JÚNIOR, V. P. da. **Sistema Agrometeorológico para Computador**. Florianópolis: COBRAC, 2004.

PETRI., J. L. et al. Dormência e indução da brotação de fruteiras de clima temperado. **Boletim Técnico**, 75. Florianópolis: Epagri, 1996. 110p.

PETRI, J. L.; PALLADINI, L. A.; POLA A., C. Dormência e indução da brotação da macieira. In: EPAGRI. **Manual da cultura da macieira.** Florianópolis, 2006.

PUTTI, G. L.; PETRI J. L.; MENDEZ M. E. Efeito da intensidade do frio no tempo e percentagem de gemas brotadas em macieira. **Rev. Bras. Frutic.,** Jaboticabal – São Paulo, v. 25, n. 2, p. 199-202, 2003.

RICHARDSON, E. A.; SEELEY, S. D.; WALKER, D. R. A model for estimating the completion of rest for Redhaven and Elberta peach trees. **HortScience**, Alexandria,v. 9, p. 331-332, 1974.

SHALTOUT, A. D.; UNRATH, C. R. Rest completion prediction model for 'Starkrimson Delicious' apples. **Journal of the American Society for Horticultural Science**, Alexandria, v. 108, n. 6, p. 957-961, 1983.

THOMAZI, Heloisa. **Atividades de produção e manejo de frutíferas de clima temperado:** estágio supervisionado obrigatório. Universidade Federal do Paraná, Pato Branco – Paraná, 2011.

WEINBERGER, J.H. Chilling requirements of peach varieties. **Proceedings of the American Society for Horticultural Science**, Geneva, v. 56, p. 122-128, 1950.