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Chilling Requirement of Ten Peach Cultivars Estimated by Different Models

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Authors' contributions

This work was carried out in collaboration between all authors. Authors CGM, FGH and MCBR designed the study, wrote the protocol and wrote the first draft of the manuscript. Authors MD, SS and JS performed the statistical analysis and managed the literature searches. Author MCBR managed the analyses of the study. All authors read and approved the final manuscript.

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ABSTRACT

The adaptation of a temperate climate fruit cultivar to a certain area depends mainly on its chilling requirement and the chilling accumulation in such places. Several attempts have been made to estimate these two conditions, using different models. The great variation among the models to calculate chilling requirement makes it necessary to determine their efficiency in a given location. Aiming to estimate the chilling requirement of ten peach cultivars, including Bonão, Pepita, Maravilha, Precocinho, Turmalina, Diamante, BR-3, Marfim, Coral, and Cambará do Sul, seven models were tested: Utah, Positive Utah, Low Chill, Taiwan, Chilling Hours (≤7.2°C), Chilling Hours (≤11°C), and Dynamic. The results showed that the estimation of chilling accumulation for all the studied cultivars in all the tested models showed a large variability. None of the tested models was

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perfect for estimating the chilling requirement, especially considering the variable climatic conditions of southern Brazil. Except for the Utah model, any of the others can be used to provide a rough estimate of the chilling requirement of the cultivars; however, the Taiwan and Low Chill models seem to be more suitable. The chilling requirement, which was estimated based on the average over the 11 years of the study, overestimated the real need, when compared to the yields over those years. There are differences among the studied cultivars; however, with the exception of Cambará do Sul, all the others can yield good crops and show good adaptation to the climatic conditions of the southern Rio Grande do Sul.

Keywords: Prunus persica; adaptation; chill units; chill hours; chill portions; dormancy.

1. INTRODUCTION

Peach (*Prunus persica* L. Batsh) is a typical temperate fruit which has experienced a great expansion worldwide, and is, presently, cultivated in subtropical areas and in the highlands of tropical regions. Thus, climatic adaptation, especially the chilling requirement, is very important and one of the top priorities of most breeding programs. The adaptation concept is related to the way plants survive and reproduce in a specific environment [1].

Climatic adaptation has become even more important over recent years because, according to several scientists, global warming may put at risk fruit tree production in the coming decades in various temperate and subtropical regions throughout the world [2,3,4]. This risk is associated with the lack of adaptation of the dormancy/growth cycle to future climatic conditions and is mainly related to a higher frequency of spring frost and insufficient chilling accumulation caused by high temperatures in winter [5]. The lack of chill accumulation during the dormancy phase of the peach causes a reduction in vegetative growth and productivity [6,7].

Several models have been proposed to study the suitable conditions for each species and cultivar and to explain the progression of the dormancy phase, starting with its induction and continuing until its complete suppression [8,9].

The choice of the appropriate model for a certain region requires a comparison among models over several years. The first model proposed was the Chill Hours (CH) [10] model, the number of hours below or equal to 45°F (7.2°C), which is still used today by several researchers. Another well-known model was published in 1974, the Richardson or Utah model [11], which refers to chill units (CU) instead of CH and considers the relative efficiency of temperature intervals. However, both models originated from experiments carried out with high chill cultivars grown in high chill accumulation regions. Thus, researchers located in warm production areas began using the modified Weinberger model, considering CH as temperatures below 11°C [12]. Meanwhile, other models using CU were developed for mild winter areas, such as the Positive Utah model [13], which is a modification of the original Utah model [11] and excludes the negation influence of high temperatures, the Taiwan model [14], and the Low Chill model [15]. The Dynamic model, using a different measure expressed as chill portions, is also considered as suitable for providing a good estimation of chilling accumulation [16]. Aiming to better estimate the chilling requirement of new varieties, researchers the world over have been using one of these models or adaptations of them [17,18,19,20].

The objective of this work was to estimate the chilling requirement of ten peach cultivars using seven mathematic models.

2. MATERIALS AND METHODS

A total of ten peach cultivars, known to have different chilling requirements, were used in this study: Bonão, Precocinho, Pepita, Maravilha, BR-3, Coral, Diamante, Turmalina, Marfim, and Cambará do Sul (Table 1).

Data of hourly temperatures were obtained from the files of the Agrometeorology Station of Embrapa Clima Temperado for the years 2004 to 2014.

The chilling requirement was calculated from May 1st until the beginning of leafing (at least 10% of lateral buds on the green tip stage) and full bloom (50% or more opened flowers). The beginning of blooming is difficult to determine in some years due to irregular flowering, and it mainly occurs when fall temperatures remain high for a long period of time. For that reason, the full bloom date was used.

Production rates were obtained from Embrapa´s files. The production of each cultivar for each year was rated before thinning on a scale 1 to 5, as follows: 1. Plants have only a few fruits; 2. Low production per plant; 3. Plants have a good production, but almost no thinning is necessary; 4. Very good production, needing fairly heavy thinning and; 5. Excessive production.

The chilling requirements of the ten peach cultivars were estimated by the following models: Utah [11]; Positive Utah or Infruitec [13]; Low Chill [15]; Taiwan [14]; Chilling Hours ≤7.2°C [10]; Chilling Hours ≤11°C [12]; and Dynamic [16].

CU are the chilling measure used by the Utah, Positive Utah, Low Chill, and Taiwan models (Table 2). The Chilling Hours models use CH, the result of the addition of either the hours equal to or below 7.2°C or the hours equal to or below 11°C. The Dynamic model uses chill portions as its unit of measurement. In the present paper, the chilling portions were converted into CU, considering each chill portion equivalent to 28 h of temperature below 6°C [21].

The average chilling requirement for vegetative bud breaking and full blooming were compared using the Student's *t*-test. The data for the chilling requirements of the cultivars for each model were submitted to variance analysis, using years as replications. The Scott-Knott test was used for means grouping of the chilling requirements for each cultivar in each of the tested models [22] after tests for normality and homoscedasticity.

Table 1. Parentage, fruit purpose, flesh color, average full bloom and beginning of ripening of ten peach cultivars, Embrapa Clima Temperado, Pelotas-RS, Brazil

Cultivar	Parentage	Fruit purpose	Flesh color	Full bloom[1]	Ripening [2]
Bonão	Conserva 594 x 'Pepita'	Canning	Yellow	Jun 22	Nov 6
Pepita	('Precocinho') OP[3]	Canning	Yellow	Jul 29	Nov 5
Maravilha	'Sunred' x FLA28.48	Table	White	Jul 17	Nov 7
Precocinho	('Diamante') OP	Canning	Yellow	Jul 19	Nov 8
Turmalina	Conserva 334 x Conserva 594	Canning	Yellow	Jul 22	Nov 20
Diamante	'Convênio' x ('Cardeal' x 'Aldrigh') OP	Canning	Dark yellow	Aug 5	Dec 4
BR-3	('Pala') OP	Table	White	Jun 4	Nov 27
Marfim	'Coral' x 'Gang Shan Zuo Sheng'	Table	White with red on the pit	Aug 12	Dec 15
Coral	('Delicioso' x 'Interlúdio') OP	Table	Greenish white with light red spots	Aug 22	Dec 3
Cambará do Sul	Unknown	Table	White	-	-

[1]Average date of full bloom and [2]beginning of ripening, based on 5 years of observations; [3]OP = Open Pollinated

Table 2. CU for temperature intervals according to four different chilling accumulation models

CU	Temperature (°C)			
	Utah model [11]	**Positive Utah model [13]**	**Low Chill model [15]**	**Taiwan model [14]**
0.0	<1.4	<1.4	<-1.0	-
0.5	1.5 ~ 2.4	1.5 ~ 2.4	1.8 ~ 7.9	-
1.0	2.5 ~ 9.1	2.5 ~ 9.1	8.0 ~ 13.9	<7.2
0.5	9.2 ~ 12.4	9.2 ~ 12.4	14.0 ~ 16.9	7.3 ~ 15.0
0.0	12.5 ~ 15.9	>12.5	17.0 ~ 19.4	15.1 ~ 26.6
-0.5	16.0 ~ 18.0	-	19.5 ~ 20.4	26.7 ~ 27.8
-1.0	>18.0	-	>20.5	>27.8

3. RESULTS AND DISCUSSION

In the present study, when comparing the chilling accumulated until vegetative bud breaking with the accumulation for full bloom, there were not significant differences found with the Student's *t*-test ($p>0.05$) for the ten peach cultivars over the 11 years of the study (data not shown). This result agrees with the statement that, in peaches, flower buds seem to have a similar chilling requirement to lateral vegetative buds, but higher than terminal buds [23]. Thus, all the results referred to from this point are based on the beginning of vegetative bud breaking, since it seems to be less erratic for the climatic conditions of the south of Brazil, where the work was developed. This is unlike other studies which use the blooming date for calculations to estimate the chilling requirements for overcoming dormancy in stone fruits, such as peaches (*Prunus persica*) [24,25,26], apricots (*P. armeniaca*) [26], almonds (*P. dulcis*) [27], and several other crops.

The variation among years for the same cultivar was very large for all of the tested models. This variability can be attributed to ecodormancy, and it is due to the negative correlation existent between the chilling requirement and the necessity of growing degree hour accumulation for dormancy suppression [28]. Similarly, all the models presented high variability for the same cultivar in the series of years studied; overall, the Taiwan and Low Chill models had the lowest coefficients of variations (CV), but they were still high (Table 3).

Using the Tabuenca test with these same cultivars [29], estimations of chilling requirement were made based on this biological method [30] for flower buds and detached twigs for vegetative buds. The results were always lower than the results obtained here. This might be due to the ecodormancy phase, which is excluded on the biological tests. Another interesting finding was that the differences between the two estimations of chilling requirements (the one based on biological tests and the one based on phenology) were reduced when the CU were calculated by the Taiwan model.

Most models made it possible to separate the cultivars into two groups according to their chilling requirements for vegetative bud break (Table 3). The exceptions were the Utah model, which did not show differences among the different cultivars, and the Taiwan model, which separated them into three groups.

The three groups formed by the Taiwan model were as follows: Cambará do Sul and Coral which constituted the cultivars with the highest chilling among the ones studied; Marfim, BR-3, and Diamante as the intermediate group; and the third group of lower chilling requirements which consisted of Turmalina, Precocinho, Maravilha, Pepita, and Bonão. Considering the different areas and sites where these cultivars are being grown, these three classes of cultivars are in agreement with their behavior in these sites (Table 3).

All models rank the cultivars based on the average chilling requirement calculated in nearly the same order. Using the Taiwan model, Bonão has the lowest chilling requirement (between 500 and 600 CU); followed by Pepita, Maravilha, Precocinho, and Turmalina (between a little over 700 and 800 CU); then Diamante, BR-3, and Marfim (between 900 and 1000 CU); and, finally, Coral and Cambará do Sul (with more than 1100 CU) (Table 3).

They were calculated for each cultivar and for each year in the seven models, but only the detailed data of the Low Chill and Taiwan models (Table 4) are shown because they are the ones with the lowest variation, they were more stable, and they were considered the ones considered the most suitable for the climatic conditions of southern Brazil.

The CU which accumulated until the beginning of vegetative bud break, as estimated by the Low Chill model, varied from 343 CU for Bonão in 2005 to 1873 CU for Cambará do Sul in 2011. When calculated using the Taiwan model, the range went from 369 CU for Bonão in 2005 to 1417 CU for Cambará do Sul in 2011 (Table 4).

The lowest variation coefficients for all cultivars, in the series of studied years, were 25.7% and 26.1%, estimated by the Taiwan and Low Chill models, respectively (Table 3), which can still be considered high. Considering this, we believed that it would be interesting to compare the chilling accumulation with the obtained crop each year, in order to set a minimum accumulation necessary for a reasonable yield. Comparing the chilling accumulation with the production rates obtained since 2005 (Table 5) some assumptions can be made.

Table 3. Average chilling requirement and CV for vegetative bud breaking of 10 peach cultivars over 11 years, Embrapa Clima Temperado, Pelotas-RS, Brazil

Cultivars	Chilling accumulation models													
	Utah		Positive Utah		Low Chill		Taiwan		Chilling Hours				Dynamic[1]	
									≤7,2°C		≤11°C			
	$\bar{x}^2$ (CU)	CV1 (%)	$\bar{x}$ (CU)	CV1 (%)	$\bar{x}$ (CU)	CV1 (%)	$\bar{x}$ (CU)	CV1 (%)	$\bar{x}$ (CH)	CV1 (%)	$\bar{x}$ (CH)	CV1 (%)	$\bar{x}$ (CU)	CV1 (%)
Bonão	46.6ns	551.7	423.2 a	36.2	703.8 a	29.1	566.5 a	24.3	142.3 a	77.7	471.1 a	38.7	532.0 a	35.4
Pepita	118.1	271.7	552.8 a	42.4	875.5 a	25.2	710.8 a	28.1	204.3 a	76.9	615.5 a	43.9	687.3 a	40.6
Maravilha	124.9	240.8	556.8 a	39.6	882.9 a	26.9	715.2 a	27.5	203.8 a	72.4	620.4 a	40.9	692.4 a	38.6
Precocinho	139.9	239.0	580.6 a	43.1	916.9 a	28.7	742.5 a	30.2	216.4 a	74.0	646.1 a	44.7	720.4 a	42.4
Turmalina	183.7	188.2	636.7 a	38.4	999.6 a	24.0	814.4 a	25.6	249.6 a	65.6	717.8 a	39.3	801.8 a	37.3
Diamante	228.0	177.5	695.3 a	43.4	1061.7 a	33.2	911.0 b	32.2	294.5 b	64.5	818.8 b	44.5	875.6 a	43.4
BR-3	265.0	148.4	780.4 b	30.6	1178.7 b	22.0	966.3 b	21.2	305.3 b	54.7	879.2 b	32.5	982.6 b	30.8
Marfim	287.8	151.7	811.0 b	41.4	1232.2 b	31.4	1002.9 b	30.6	313.5 b	59.0	914.5 b	43.3	1018.2 b	41.8
Coral	324.8	131.4	911.9 b	28.7	1357.3 b	20.8	1114.4 c	19.4	354.0 b	46.7	1025.6 b	30.4	1137.8 b	29.5
Cambará do Sul	295.5	163.2	978.9 b	27.1	1455.8 b	19.6	1188.2 c	17.7	371.4 b	43.7	1098.8 b	28.5	1221.8 b	27.1
CV2 (%)	186.7		36.8		26.1		25.7		61.1		38.4		36.6	

[1]The chilling portions were converted into CU for comparison with other models [21]; [2]Averages followed by the same letter in the columns form the same cluster by the Scott-Knott test (p>0.05); ns = non-significant; CU = Chill units; CH = Chill hours; CV1 = Coefficient of variation for chilling requirement calculated to same cultivar using the tested models; CV2 = Coefficient of variation between cultivars for the same model

Table 4. CU accumulated to vegetative bud breaks, calculated by the Low Chill model and by Taiwan model, for 10 peach cultivars in years 2004 to 2014, Embrapa Clima Temperado, Pelotas-RS, Brazil

Year	CU for cultivars calculated by the Low Chill model									
	Bonão	**Pepita**	**Maravilha**	**Precocinho**	**Turmalina**	**Diamante**	**BR-3**	**Marfim**	**Coral**	**Cambará do Sul**
2004	609	629	591	609	854	591	1109	1003	1238	1440
2005	343	475	455	455	540	598	798	455	943	943
2006	695	844	855	844	844	880	871	922	1061	1331
2007	853	1043	1003	1079	1226	844	1379	1682	1658	1831
2008	835	886	878	886	963	1045	1214	1285	1381	1534
2009	836	1121	1121	1184	1297	1450	1397	1573	1450	1580
2010	800	899	1141	1123	1157	1440	1466	1564	1564	1564
2011	987	1241	1241	1359	1359	1566	1542	1645	1832	1873
2012	381	929	809	915	929	988	990	1071	1102	1198
2013	820	888	884	926	965	1419	1292	1410	1564	1583
2014	583	675	734	706	862	858	908	944	1137	1137
$\overline{X}$	703.8	875.5	882.9	916.9	999.6	1061.7	1178.7	1232.2	1357.3	1455.8
SD	204.4	220.9	237.2	263.5	240.2	352.1	258.8	386.7	282.4	284.8
CV (%)	29.1	25.2	26.9	28.7	24.0	33.2	22.0	31.4	20.8	19.6
Year	**CU for cultivars calculated by the Taiwan model**									
	Bonão	**Pepita**	**Maravilha**	**Precocinho**	**Turmalina**	**Diamante**	**BR-3**	**Marfim**	**Coral**	**Cambará do Sul**
2004	459	475	449	459	688	449	856	792	968	1112
2005	369	492	471	471	556	601	811	471	905	905
2006	510	631	637	631	631	668	686	736	873	1095
2007	824	1036	1006	1054	1181	1259	1299	1518	1506	1610
2008	565	619	619	619	670	720	835	887	967	1068
2009	655	896	896	968	1058	1157	1116	1239	1157	1260
2010	575	707	897	883	917	1167	1184	1263	1263	1263
2011	761	917	917	1003	1003	1177	1161	1237	1389	1417
2012	500	926	816	912	926	981	986	1048	1078	1168
2013	583	618	620	645	679	1180	988	1107	1256	1276
2014	430	502	539	522	649	662	707	734	896	896
$\overline{X}$	566.2	710.8	715.2	742.5	814.4	911.0	966.3	1002.9	1114.4	1188.2
SD	137.5	199.8	196.8	224.5	208.6	293.6	204.6	306.7	216.1	210.6
CV (%)	24.3	28.1	27.5	30.2	25.6	32.2	21.2	30.6	19.4.6	17.7

$\overline{X}$ = Average; SD = Standard Deviation; CV = Coefficient of Variation.

Table 5. Degree of production on a scale 1 to 5, for the nine peach cultivars from year 2005 to 2014, Embrapa Clima Temperado, Pelotas-RS, Brazil

Cultivar[1]	Degree of production per year[2]									
	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Bonão	1	-	3	3	3	3	4	5	2	1
Pepita	-	3	4	4	2	4	4	3	3	4
Maravilha	-	3	-	5	5	4	4	4	1	1
Precocinho	3	3	4	5	3	3	5	5	2	4
Turmalina	2	3	4	3	4	3	5	5	4	4
Diamante	2	3	3	2	2	2	3	5	4	4
BR-3	-	2	3	4	4	2	4	5	5	5
Marfim	-	3	4	5	4	3	5	5	5	5
Coral	-	4	3	5	3	-	4	5	5	3

[1]Cambará do Sul was not included because it did not have good production in the evaluated years; [2]Degree of production per year: 1. Very low production; 2. Low production; 3. Good to medium production; 4. High production; 5. Excessive production

The year 2007 had the coldest winter, and 2014 had the warmest winter of the 11 studied years. However, most cultivars produced a similar or even better crop in 2014 than in 2007. This supports the statement that cultivars released for subtropical climates can satisfy their chilling requirement for dormancy breaking at higher temperatures than ones developed for use in colder regions [31]. In other words, higher temperatures are effective in the dormancy breaking of subtropical cultivars.

Observing the yearly chilling accumulation until the beginning of leafing for each cultivar (Table 4), it can be assumed that Bonão had the chilling requirement satisfied with less than 500 CU, as estimated by the Taiwan model, since it had an excessive production in 2012 (Table 5) with this chilling accumulation. The lowest CV for this cultivar was the Taiwan model (24.3%), followed by the Low Chill model (29.1%). Likewise, the lowest coefficient of variation for chilling accumulation over the years for the all cultivars was obtained with these two models.

Pepita only had low productivity in 2009 (Table 5), probably due to frost, because, even with an accumulation of 502 CU (Taiwan model) or 675 CU (Low Chill model) in 2014, the production was high. Comparing the production rates of cv. Precocinho (Table 5) and the chilling accumulation, we can conclude that 455 CU (Low Chill model) or 471 CU (Taiwan model), in 2005, were enough for this cultivar to produce a commercial crop (Table 4).

Maravilha had an average of 882.9 CU (Low Chill model) or 715.2 CU (Taiwan model) with standard deviations of 237.2 and 196.8, respectively. However, 619 CU were enough for a very good crop in 2008 (Taiwan model). Thus, using the same type of approach, we estimated that BR-3 had enough chilling in 2014, considering the very high production with 908 CU or 707 CU using the Low Chill or Taiwan model, respectively (Table 4).

In the case of Coral, it had very good production when the chilling accumulation until first leafing was 873 CU (Taiwan model). Using this same model for Diamante and Turmalina, 662 CU and 631 CU, respectively, allowed good production (Tables 4 and 5).

Marfim had an average chilling accumulation until the beginning of the vegetative bud break of 1002.9 CU and 1232.2 CU, as estimated by the Taiwan and Low Chill models, respectively. However, 734 CU (Taiwan model) in 2014 were sufficient to assure a good crop (Tables 4 and 5).

There was not any production data available for Cambará do Sul. This is a late ripening genotype, of unknown origin, with a very low fruit set and, due to weather conditions at the time of fruit ripening, the fruits are usually knocked down by brown-rot (*Monilinia fructicola*).

It is interesting to point out that once the chilling requirement is satisfied, the bud breaking does not start immediately for all cultivars. The external temperatures may not be favorable, and the warm temperature accumulation may not have reached the desired amount for all of them. The chilling requirement and the warm temperatures needed for bud break have a significant negative correlation [25].

Biological tests, such as detached twigs [30] or the single bud test, should be conducted in order to validate the results presented here.

4. CONCLUSION

The estimation of chill accumulation for all the studied cultivars by all of the tested models has a large variability.

None of the models is perfect for southern Brazil's conditions.

Except for the Utah model, any of the other models can be used to give a rough estimate of the chilling requirements of the cultivars; however; the Taiwan model, followed by the Low Chill model, seem to be the most suitable.

Based on the Taiwan model estimations and the obtained crops over the years, Bonão Pepita and Precocinho require less than 500 CU. Diamante, Turmalina, BR3, and Maravilha require between 600 and 700 CU, and Coral and Marfim require between 770 CU and 870 CU.

The chilling requirement estimated, based on the average over 11 years, overestimated the real need.

There are differences among the studied cultivars; however, with the exception of Cambará do Sul, all of the other cultivars can yield good crops and show good adaptation to the for Pelotas and similar climatic areas.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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