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Historical Chill Hour vs Chill Portions Analysis in the Southeast United States for Better Dormancy Breaking Assessment in Peach

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Abstract

The Chill Hour (CH) model has traditionally been used to report and calculate chill requirements (CR) for dormancy breaking in temperate crops like peach and nectarine. However, this model oversimplifies the tree's response to weather fluctuations and fails to adequately assess CR fulfillment, making it challenging to determine if the reported CH requirement for peach cultivars has been met. The Chill Portions (CP), or Dynamic model, offers a more precise assessment of chill accumulation, especially in warmer regions, and should be used for CR reporting and estimation in tree fruits. There is no simple way of converting CH to CP accumulation for cultivars whose CR is reported in CH without forcing and weather data. To support using CP in CR assessment, we developed a conversion chart between CH and CP for peach cultivars by analyzing CP accumulation for every 50 CH increments over thirty years (1989-2019) using weather data from three different weather stations across the Carolinas and Georgia (KRDU, KGSP, KABY). The implications and need of using the CP model when determining the chilling requirement of future cultivar releases are discussed.

Warm winter temperatures are increasingly restraining peach growers in the southeast U.S. in selecting cultivars with appropriate dormancy requirements. Climate modeling showed a .5°C increase in minimum winter temperatures in the southeast in the last 30 years, 1992-2022 (NOAA, 2023), resulting in frequent seasons with insufficient chilling accumulations (Parker and Abatzoglou, 2019). Incomplete chill satisfaction can be detrimental to peach growth by reducing flower viability and changing bloom timing and duration, causing abnormal bud break, fruit growth and ripening, and advancing leaf senescence. These challenges can significantly impact disease management, harvest operations, and the desired fruit quality and yield (Popenoe 2017). The complex relationship between chill requirement (CR) and its counterpart, heat requirement (HR), and their effect on floral and leaf bud-break is still largely unknown despite being well-researched (see reviews Goeckeritz and Hollender 2021; Yamane et al., 2023). Moreover, the way trees count and accumulate chill, and models to quantify chilling accumulation were proposed almost five decades ago (Weinberger, 1950; Richardson et al., 1974; Fishman et al., 1987a,b).

The three models, Chill Hour (Weinberger, 1950), Utah (Richardson et al., 1974), and Dynamic model (Fishman et al., 1987a,b), differ in the method of estimating chilling accumulation. The Chill Hour (CH) model has long been the standard for determining the regional success of cultivars used in peach pro-

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duction and in reporting the chill requirement of newly released cultivars. It simply uses the sum of hours when temperatures fall between 0-7.2°C. The Utah model, developed to correct address shortcomings of the CH model (Richardson et al., 1974), reports CR in chill units and assigns different weights of chilling according to the temperature ranges. It also includes negation of chilling accumulation with high temperatures during dormancy. There are variations of this model, such as the Positive Utah model, that were developed to account for regional differences and better represent ecological region (Linsley-Noakes and Allan, 1994).

The most complex and presently most accurate model capable of compensating for the temperature fluctuations is the Dynamic model that reports chill accumulation in chill portions (CP) (Fishman et al., 1987a,b). It differs from the Utah model as it assumes a two-stage process in winter chill accumulation. First, cold temperatures result in a creation of an intermediate chilling product, which can still be negated if succeeded by high temperatures in the following daily cycle. However, once enough of the chilling product has accumulated it is converted into a chill portion that cannot be negated. The Dynamic model has proven to be the most accurate model in estimating chilling accumulation of several temperate crops such as peach, (Allan et al., 1995; Erez et al., 1990) and pistachio (Zhang and Taylor 2011) and less variable from year to year than CH, especially in warmer climate (Egea et al. 2021; Louw et al. 2023). All these models provide just estimations of chill accumulations, as the full understanding behind the stages and processes of dormancy, and particularly the temperature's effect on those processes is still lacking, and as such, the vindication of these models relies heavily on field observations (Luedeling et al. 2009). In addition, a more important issue that is somehow neglected, is how CR is estimated and reported for the cultivars when they are released.

Almost all cultivars' descriptions report CR in chill hours, and it is not clear if the CR was estimated by forcing, examining if the winter weather was sufficient to allow the tree to have normal bloom and budbreak and reporting total estimated accumulation of chill hours for the season, or by comparing bloom time and budbreak observations with a cultivar with a "known" CR (Okie 1998). Breeding efforts to develop peach cultivars with lower CR, for warm winters, and increased HR, to delay bloom and avoid potentially devastating frosts, are underway (Gasic et al. 2022). However, most breeders are still using chill hours as their accumulation model if reporting CR at all. This loose CR reporting is mixed in literature and patenting documentation that complicates choosing the right cultivar for the ecological region and predicting if the current season provides adequate chill for already planted cultivars. This also poses difficulty for breeders looking for diverse germplasm to combat the climate crisis through selective breeding. The burden of proper evaluation of cultivar adequacy for the region often falls on county agents or growers via local or regional trials, but CR is rarely empirically determined. The only attempt to provide estimated CP values for CH accumulation was based on field observations and weather data specific to a single location (Reighard and Vinson 2019).

Therefore, we aimed to evaluate the consistency between the CH and the CP accumulation over 30 years within the southeast U.S. and develop CH to CP conversion chart supported by the weather data. The goal of this study was to provide an interim document that is based on the weather data to assist growers, county agents and researchers in assigning CP to peach cultivars with CR reported and emphasize the need for all parties to utilize the most appropriate model for chill accumulation for the region.

Materials and Methods

Hourly temperature data spanning from 1989 to 2019 was obtained from three climatically distinct weather stations KABY, KGSP, and KRDU (Bielenberg and Gasic 2022). All stations were selected due to their geographical span across the largest peach production states in the southeast, that also had reliable, historical, hourly weather data. KABY is located at the Southwest Georgia Regional Airport, in Albany Georgia. (31°32'08"N 84°11'40"W), KGSP is located at the Greenville Spartanburg International Airport, in Greer South Carolina (34°53'44"N 82°13'08"W) and KRDU is located at the Raleigh-Durham International Airport, in Cedar Fork Township, North Carolina (35°52'40"N 078°47'15"W).

The CH and CP accumulation were calculated from October 1st to the end of February for each dormancy season using <7.2ºC Weinberger (1950) model and the Dynamic Model (Erez et al. 1990), respectively, built in the excel sheet developed by Fishman et al. (1987a,b).

The CP range was analyzed at 50 CH intervals up to 1000, across all three stations during the 23 years with complete data (Fig. 1). Station CP means for each 50CH interval were compared with ANOVA and statistical significance determined using Tukey HSD. Statistical analysis was performed using JMP® *Pro 17* (SAS Institute Inc., Cary, NC). Greenhouse forcing of field-collected shoots was performed for 14 cultivars from Clemson University peach germplasm collection during winter of 2021/2022. Once trees entered dormancy shoots were collected at the 100 CH increments starting at 24, 28, 34, 39, 43, 48, and 54 CP and put into greenhouse to provide adequate HR (Gibson and Reighard, 2002). CR was deemed satisfied if >50% of the floral buds bloomed, and results of the forcing data was compared to the estimated minimum and median CP from the historical dataset (Table 2). The hourly temperature data were obtained from the weather station at the Clemson University's Musser Fruit Research Center in Seneca, SC (34°37'.062"N 82°53'13"W).

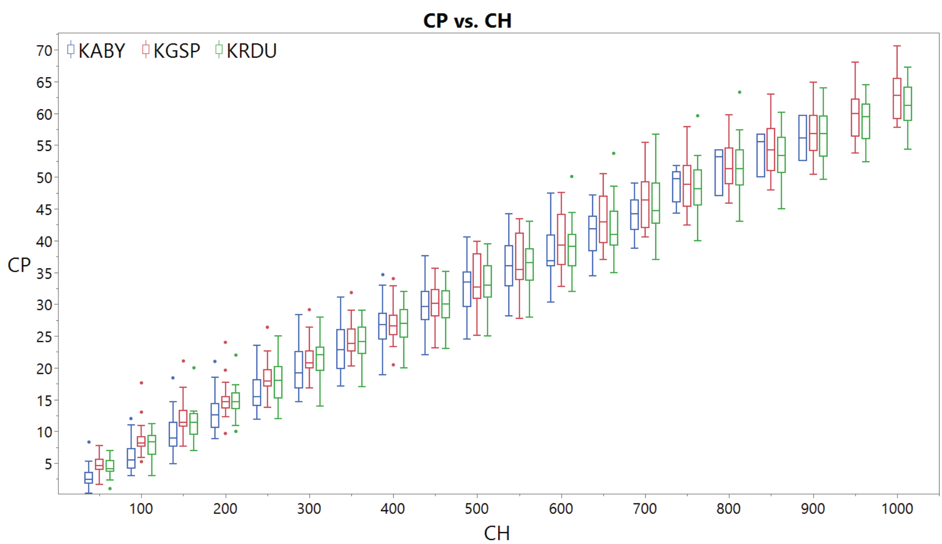

Figure 1. Chill portion (CP) range at 50-chill hour (CH) intervals at three different weather stations. The line inside the box represents the median value, the lower and upper lines represent the 25th and 75th percentile. Whiskers show the lower and upper values while dots represent extreme outliers.

Results and Discussion

The weather data obtained from the three weather stations across the southeast during the dormancy season showed variation in agreement with the weather station locations (Bielenberg and Gasic, 2022). The most southern weather station, KABY, never reached chill hour accumulation over 900 CH. The calendar date was used as a start for counting chill accumulations even though other options, such as when the tree is at 50% defoliation (Guerriero et al., 2006), the day after maximum negation (Richardson et al., 1974), or the biological indicators, such as phenological data (e.g., date of endodormancy release) (Egea et al., 2021), are proposed as more accurate. However, that information was not available for peach trees in the three geographical regions and the time period (1989-2019) considered in this study. The most common date to start counting chill accumulation in the southeast U.S. is 1 Nov but it was not chosen as it would not account for early chill accumulation in the most north station (KRDU). Therefore, calendar date of 1 Oct was deemed as the best alternative to capture chill hour accumulation in all three geographical regions.

CP distribution varied at different CH intervals with all three weather stations exhibiting a positive relationship between CH and CP. Consistent skewing towards lower or higher CP is broken up by equilibrium periods in which box plot medians were symmetrical. Distribution and spread tended to increase as chill hour intervals increased. Most outlying points were distributed along the lower end of the graph, at and below 400 CH, with only KRDU having outliers above 600 CH (Fig. 1). This suggested that CP predictions using CH accumulation may be less reliable and more difficult to predict at lower CH which supports previous observations that Dynamic model is less accurate in the warmer climate

Table 1. Chill hour (CH) to chill portion (CP) conversion chart. CP interval (based on 95% Confidence Interval (CI)) and Median values at 50-CH intervals were recorded from 1989-2019 at three southeastern weather stations (KABY, KGSP, and KRDU).

CH	*CP range*			*Proposed CP*	
	KABY	**KGSP**	**KRDU**	**95% CI**	**Median**
50	0-8	2-8	1-7	[3.6,4.4]	4
100	3-12	5-18	3-11	[7,8]	8
150	5-18	8-21	7-20	[10,12]	11
200	9-21	10-24	10-22	[14,15]	14
250	12-24	14-26	12-25	[17,18]	18
300	15-28	17-29	14-28	[20,22]	21
350	17-31	20-32	17-29	[23,25]	24
400	19-35	20-34	20-32	[26,28]	27
450	22-38	23-36	23-35	[29,31]	30
500	24-41	25-40	25-39	[32,34]	33
550	28-44	28-43	28-43	[35,37]	36
600	30-47	33-48	32-50	[38,40]	39
650	34-47	37-51	35-54	[41,43]	42
700	39-49	41-55	37-57	[45,47]	45
750	44-52	42-58	40-60	[48,50]	49
800	47-54	46-60	43-63	[50,53]	51
850	50-57	48-63	45-60	[53,55]	54
900	53-60	50-65	50-64	[56,58]	57
950	-	54-68	52-65	[58,60]	60
1000	-	58-71	54-67	[61,63]	62

(Louw et al. 2023). Similarly, the differences between CP among stations were statistically significant with $P < 0.05$ only at low chill hour intervals (less than 250 CH). The three stations had the most similar distribution at 450 CH (Fig. 1). KRDU, representing the coolest climate range, had significantly lower CP minimums at CH exceeding 650 CH, and was the only station with outlier points at higher chill hour intervals (above 600 CH), which may reflect abnormally cold seasons. KABY's 30-year CP range reflected lower CP accumulation than that at KGSP and KRDU at the same CH. KGSP had comparatively higher CP range recorded at each CH except for the 600-800 CH period in which KRDU had high outliers (Fig. 1).

The conversion chart developed in this study suggest that low chilling cultivars (less than 400 CH) and moderate chilling cultivars (around 700 CH) would have their requirements fulfilled around 27 and 45 CP, respectively, while high chill cultivars (above 850 CH) would need at least 54 CP to satisfy endo-dormancy chilling demand (Table 1). Proposed CP from the historical dataset in this study is supported by field observations and provides a clear representation despite seasonal irregularities (Reighard and Vinson 2019). Empirical evidence shows slightly lower CP requirements than the mean value obtained by conversion, which could be explained by the differences between optimum CR fulfillment and critical CR, and the overlap between CR and HR. The potential overlap between CR and HR suggests that if chilling hasn't been fully satisfied, but a critical CR has been met, a combination of chill and heat units can still result in budbreak (Harrington et al. 2009). The slight discrepancy, of about 5-10 CP, with Reighard and Vinson (2019) study might also be due to the accuracy of the CH accumulation assessment. Reighard and Vinson (2019) used field observations and weather station near Chilton County Research and Education Center, where peach research is conducted, while this study utilized historical weather

Table 2. Estimated and observed chill portion (CP) requirement for 14 peach cultivars with different ripening season and chill hour (CH) requirement. The chill portion (CP) minimum and median were estimated from 1989-2019 weather data collected at three southeastern weather stations (KABY, KGSP, and KRDU). Observed CP requirement was obtained by greenhouse forcing in 2021/2022 season. RV CP - Reighard and Vinson (2019) CP estimate (https://ssl.acesag.auburn.edu/dept/peaches/peachipm/).

Cultivar	Season	CH	RV CP	Estimated CP		Observed CP
				Min	Median	(2020/21)
Goldcrest	Early	650		34-37	42	28
Juneprince	Early	650	30-35	34-37	42	39
PF23	Mid	650		34-37	42	39
Scarletpearl	Early	750		40-44	49	48
Bounty	Mid	800	35-40	43-46	51	48
O'Henry	Late	800	35-40	43-46	51	48
Caroking	Mid	850		45-50	54	39
Rich Joy	Late	850		45-50	54	48
Summerprince	Mid	850		45-50	54	34
Julyprince	Mid	850	40-45	45-50	54	48
Flameprince	Late	850	40-45	45-50	54	43
Augustprince	Late	850		45-50	54	48
Redhaven	Mid	950	45-50	52-54	60	54
Intrepid	Mid	1000	45-50	54-58	62	48

data from commercial weather stations (e.g., KGSP and KRDU, near airports) that are not in vicinity of the peach orchards. In addition, greenhouse forcing experiments of 14 cultivars from Clemson University peach germplasm during a single season showed similar CP requirements as proposed by the conversion chart (Table 2). However, this is just a snapshot of one season CR observations and should be supported by the multiple observations to account for year-to-year variability (Pantelidis and Drogoudi 2023).

Choosing a model that best accounts for CR accumulation is constrained to where and how the weather data are sampled. The chilling accumulation models require hourly temperature data, which influenced the choice of the weather stations in this historical overview and affected accuracy when compared to the weather data obtained from true field growing conditions. It is suggested that local variations in temperature, especially associated with landscape features such as elevation or aspect can influence CR accumulations (Cooke et al., 2012). With winter temperatures increasing, the Dynamic model tends to be more accurate for chilling accumulation predictions in various temperature fruit crops, like pistachio (Zhang and Taylor 2011), and cherry (Luedeling et al. 2009). This conversion chart is developed for one purpose only, to assist growers and researchers in expressing chilling requirement of cultivars for which this information is lacking. This work just adds to the number of recent studies emphasizing the need to improve the way CR is reported and to the significance of using Dynamic model to calculate and express CR in describing newly released cultivars under the present and future forecasted climate in the southeast U.S. as well as in other parts of the world with warmer climate (Egea et al. 2021).

Conclusions

Breeding for climate resilience and choosing cultivars that fit the local environment requires accurate CR information. Descriptions of peach cultivars released up-to-date do not provide CR information that can easily be applied to the changing climate. To accommodate for lack of this information we developed the CH to CP conversion chart for the southeast U.S. using weather data and tested its accuracy via greenhouse forcing validations. Going forward, regional weather data, that accurately depict growing conditions, and biological indicators of the endodormancy start will need to be used to determine chilling requirement of the newly released peach cultivars. Correctly predicting chill accumulation will allow for selection of cultivars that are suited for growing region, and lead to a more productive and reliable crop.

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