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Prediction of full blooming dates of five peach cultivars (*Prunus persica*) using temperature-based models

Jong Ahn Chun[a,*], Kwangmin Kang[b], Daeha Kim[a], Hyun-Hee Han[c], In-Chang Son[d]

[a] *Climate Application Department, APEC Climate Center, 12 Centum 7-ro, Haeundae-gu, Busan, 48058, Republic of Korea*
[b] *National Oceanic and Atmospheric Administration, 1325 East West Highway, Silver Spring, MD, 20910, United States*
[c] *Department of Horticultural Crop Research, National Institute of Horticultural and Herbal Science, 100 Nongsaengmyeong-ro, Iseo-myeon, Wanju-gun, Jeollabuk-do, Republic of Korea*
[d] *Research Institute of Climate Change and Agriculture, National Institute of Horticultural and Herbal Science, 281 Ayeonno, Jeju, Republic of Korea*

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ABSTRACT

In this study, we attempted to develop temperature-based prediction models for full blooming dates of peach cultivars through identifying models to better predict those among the developmental rate (DVR) model, chill day model, and new chill day model. The six major cultivation sites of peach trees (Chuncheon, Suwon, Cheongwon, Cheongdo, Naju, and Jinju) and five cultivars ('Cheonghong', 'Youmyeong', 'Changbangjosaeng', 'Cheonjoongdo', and 'Janghowon') were selected for this study. Three goodness-of-fit measures such as Mean Absolute Percentage Error (MAPE), R^2 (coefficient of determination), and Root Mean Square Error (RMSE) were used to evaluate the performance of those models. The new chill day models (2.12%, 0.83, and 3.02 days for MAPE, R^2 and RMSE, respectively) showed better prediction results for the entire dataset than the other models (DVR: 2.54%, 0.75 and 3.61 days and chill day models: 2.22%, 0.80, and 3.22 days for MAPE, R^2 and RMSE, respectively). The estimated parameters were also slightly different from the cultivars. However, since the number of observations could contribute to the differences of the parameters and performances, it is recommended that the number of observations for the cultivars at each site should be increased to improve the models in the future.

1. Introduction

Recently, bud-burst and flowering dates of fruit crops showed a tendency to become earlier and an increase in the variabilities of temperature in spring lead to the high risk of frost damage to fruit crops (Honjo, 2007). Since full blooming dates of peach trees are earlier than other fruit crops, the risk of peach trees can be higher than others. The accurate prediction of full blooming dates of fruit crops can be useful to reduce the damage. However, the full blooming date prediction model for peach tree used by the Rural Developmental Administration (RDA) were developed using only one cultivar ('Youmyeong') and observations from a station (Suwon, South Korea). This RDA's model might not adequately reflect the characteristics of peach cultivars or regions.

Temperature-based models including the developmental rate (DVR) model, the chill day model, and the new chill day model have been used for the prediction of bud-burst and flowering dates of fruit crops (e.g., Cesaraccio et al., 2004, 2005, 2006; Yun et al., 2012). The DVR model has been used to predict flowering dates of fruit crops (e.g., Sakamoto et al., 2015; Yun et al., 2012). Sakamoto et al. (2015) investigated the relationship between temperature and endodormancy of the Japanese chestnut 'Porotan' and developed a DVR model for the Japanese chestnut 'Porotan'. Murakami et al. (2009) showed that the prediction error resulted by the DVR model was approximately 4 days in a study on the prediction of cherry flowering date. This DVR model has been also used for the prediction of the flowering dates of Japanese pear (Sugiura et al., 1991; Sugiura and Honjo, 1997). Surgiura and Honjo (1997) reported that the DVR model accurately predicted the flowering dates with Root Mean Square Error (RMSE) of 1.23 days. Yun et al. (2012) developed the prediction model of full blooming dates of the Korean peach 'Youmyeong' and concluded that the DVR model can be useful for the prediction of full blooming dates of the Korean peach 'Youmyeong'.

Dormancy is generally divided into two periods: "rest" and "quiescence" periods (Cannell and Smith, 1983; Hanninen, 1990; Linkosalo, 2000). At the former period, buds remain dormant due to physiological conditions, and at the latter period, buds remain dormant due to environmental conditions (Sarvas, 1974). Based on the overlapping of the two periods in models, there are two models: "parallel" and

* Corresponding author.
E-mail addresses: jachun@apcc21.org, jongahnchun@gmail.com (J.A. Chun).

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"sequential" dormancy models. A parallel dormancy model is assumed that the two periods are overlapped, while a sequential dormancy model is assumed as no overlapping of both periods (Hanninen, 1987, 1990; Kramer, 1994).

Chilling and forcing models (as sequential dormancy models) have been used to predict bud-burst and flowering dates of fruit and forest species (Cesaraccio et al., 2004, 2005, 2006; Kim et al., 2013; Kuzmanova, 2015). The models were described as the chill day model (Cesaraccio et al., 2004, 2005, 2006), the new chill day model (Cesaraccio et al., 2006) and the fraction-time model (Cesaraccio et al., 2006). In the models, chill days (C_d) are accumulated until the chilling requirement (C_R) is met (i.e., breaking rest) and anti-chill days (C_a) are accumulated until $\Sigma|C_a| \geq |C_R|$ (i.e., overcoming quiescence and bud-burst). Cesaraccio et al. (2006) reported that the new chill day model showed better prediction of bud-burst of some fruit crops and forest species and the performance of the fraction-time model were better than that of the chill day model for fruit crops. Farajzadeh et al. (2010) used the chill day model to predict bud-burst of apple trees and the frost risk at bud-burst dates. They suggested that the frost risk of apple trees may increase in warmer winter seasons because the budding time may be earlier. The chill day model was used to predict times for breaking rest and overcoming quiescence for Common beech (*Fagus sylvatica*) (Kuzmanova, 2015).

A concept of heating requirement (H_R) was proposed by Jung et al. (2005) through extending the concept of anti-chill days (C_a). They defined H_R as the accumulation of C_a until flowering time of cherry trees exceeding bud-burst and used this concept to predict cherry flowering dates. Hur and Ahn (2014) projected changes in flowering dates of peach and pear trees under Representative Concentration Pathway (RCP) 4.5 and 8.5 scenarios using the chill day model and flowering times of both fruit crops would become earlier in the future. The chill day model was used for the prediction of the blooming dates of spring flowers (Kim et al., 2013).

Although some literature is available on the each model performance separately, few studies have been conducted on the comparison of those models. The objective of this study was to develop the full blooming date prediction models for major peach cultivars using the temperature-based models.

2. Materials and methods

2.1. Site description and data collection

Developmental rate (DVR) and sequential dormancy models (chill day and new chill day models) were used to develop the full blooming date prediction models for the peach cultivars at the six major peach cultivation sites. For the development of these models, bud-burst and full blooming dates of peach trees for the five cultivars ('Cheonghong': chh, 'Youmyeong': ymn, 'Changbangjosaeng': cbj, 'Cheonjoongdo': cjo, and 'Janghowon': jhw) were collected from the six major peach cultivation sites (Chuncheon, Suwon, Cheongwon, Cheongdo, Naju, and Jinju). Table 1 summarizes the observed bud-burst and full blooming dates at the six sites. Three trees in the middle of plots were selected and all of the buds in those three trees were observed. Approximately 30 of full blooming dates for the two cultivars ('Youmyeong' and 'Changbangjosaeng') were collected at the Suwon peach cultivation site from 1979. The number of observations of 'Cheonhong' at Naju was shortest as 6 from 2001 to 2007 (missing in 2002). The lowest mean burd-burst date was approximately 79 Julian days for the 'Cheonghong' cultivar at Jinu and the largest was approximately 93 Julian days for the 'Youmyeong' at Cheongwon. The mean full blooming date of 'Cheonghong' at Jinu was lowest (about 99 Julian days) and that of 'Youmyeong' at Chuncheon largest (about 114 Julian days).

Table 1
Observed bud-burst and full blooming dates in Julian day at study sites.

Site	Cultivar	Bud-burst date		Full blooming date	
		N[a]	MEAN ± STD (Julian day)	N[a]	MEAN ± STD (Julian day)
Chuncheon	chh	10	90.4 ± 2.4	10	112.3 ± 4.1
	ymn	14	89.7 ± 4.3	17	114.1 ± 5.3
Suwon	cbj	17	90.4 ± 5.1	27	111.2 ± 4.7
	chh	9	88.4 ± 3.5	9	109.2 ± 4.6
	ymn	18	90.7 ± 5.1	31	113.3 ± 4.9
Cheongwon	chh	6	89.8 ± 5.1	6	107.2 ± 6.4
	ymn	6	92.7 ± 3.8	6	111.0 ± 4.2
Cheongdo	cjo	5	89.0 ± 3.0	10	103.9 ± 3.9
	jhw	5	89.0 ± 3.0	9	103.8 ± 3.9
	ymn	8	84.9 ± 6.6	11	103.9 ± 4.1
Naju	chh	6	81.3 ± 2.6	6	101.3 ± 4.2
	ymn	7	82.3 ± 3.1	7	102.1 ± 3.5
Jinju	chh	8	78.9 ± 6.9	8	99.1 ± 5.2
	ymn	9	79.0 ± 6.6	9	102.4 ± 3.2

[a] Number of years.

Even though the weather datasets including daily maximum, minimum, and mean temperature were required to develop those prediction models, no weather stations were installed at the orchards where those dates were collected from. Therefore, those weather variables were collected from the nearest Automated Synoptic Observing System (ASOS) from the orchards. It should be noted that this limitation can contribute to the errors of the developed prediction models in this study. A further study is recommended to investigate this limitation. Fig. 1 displays these stations (Chuncheon, Suwon, Cheongju,

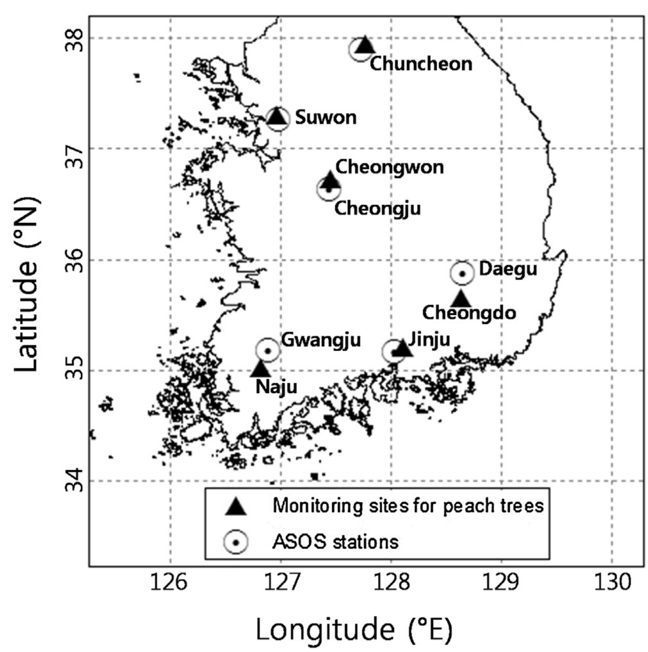

Fig. 1. Location map of Automated Synoptic Observing System (ASOS) stations nearest to monitoring sites for bud-burst and full blooming dates of peach trees in this study. Monitoring sites for bud-burst and full blooming dates of peach trees: Chuncheon (37.95°N, 127.78°E), Suwon (37.31°N, 126.98°E), Cheongwon (36.73°N, 127.46°E), Cheongdo (35.65°N, 128.65°E), Naju (35.03°N, 126.83°E), and Jinju (35.21°N, 128.12°E); ASOS stations: Chuncheon (37.90°N, 127.74°E), Suwon (37.27°N, 126.99°E), Cheongju (36.64°N, 127.44°E), Daegu (35.89°N, 128.62°E), Gwangju (35.17°N, 126.89°E), and Jinju (35.16°N, 128.04°E).

Table 2
Accumulation of chill days and anti-chill days for the five cases of the chill day and new chill day models.
Adapted from "Improvement of chilling and forcing model to predict bud-burst," by Cesaraccio et al. (2006).

Cases (°C)	Chill day model		New chill day model	
	Chill days (C_d)	Anti-chill days (C_a)	Chill days (C_d)	Anti-chill days (C_a)
$0 \le T_C \le T_n \le T_x$	$C_d = 0$	$C_a = T_M - T_C$	$C_d = 0$	$C_a = T_M - T_C$
$0 \le T_n \le T_C \le T_x$	$C_d = -\left[(T_M - T_n) - \frac{(T_x - T_C)^2}{2(T_x - T_n)}\right]$	$C_a = \frac{(T_x - T_C)^2}{2(T_x - T_n)}$	$C_d = \frac{(T_n - T_C)^2}{2(T_n - T_x)}$	$C_a = \frac{(T_x - T_C)^2}{2(T_x - T_n)}$
$0 \le T_n \le T_x \le T_C$	$C_d = -(T_M - T_n)$	$C_a = 0$	$C_d = T_M - T_c$	$C_a = 0$
$T_n \le 0 \le T_x \le T_C$	$C_d = -\left[\frac{T_x^2}{2(T_x - T_n)}\right]$	$C_a = 0$	$C_d = (T_M - T_c) - \left[\frac{T_n^2}{2(T_n - T_x)}\right]$	$C_a = 0$
$T_n \le 0 \le T_C \le T_x$	$C_d = -\frac{T_x^2}{2(T_x - T_n)} - \frac{(T_x - T_C)^2}{2(T_x - T_n)}$	$C_a = \frac{(T_x - T_C)^2}{2(T_x - T_n)}$	$C_d = \frac{(T_n - T_C)^2}{2(T_n - T_x)} - \frac{T_n^2}{2(T_n - T_x)}$	$C_a = \frac{(T_x - T_C)^2}{2(T_x - T_n)}$

T_c: Threshold temperature; T_n: Daily minimum temperature; T_x: Daily maximum temperature; and T_M: $(T_x + T_n)/2$.

Table 3
Fitted exponential models and goodness-of-fit measures for the DVR models.

Site	Cultivar	C in Eq. (2)	D in Eq. (2)	MAPE (%)		R^2		RMSE (day)	
Chuncheon	chh	0.014	0.062	1.79	1.77	0.67	0.75	2.28	2.46
	ymn	0.010	0.093	1.76		0.78		2.57	
Suwon	cbj	0.008	0.127	3.35	3.06	0.43	0.63	4.62	4.33
	chh	0.004	0.194	3.37		0.45		4.88	
	ymn	0.007	0.138	2.72		0.65		3.87	
Cheongwon	chh	0.011	0.077	2.50	3.85	0.74	0.54	3.32	5.04
	ymn	0.002	0.261	5.20		0.68		6.31	
Cheongdo	cjo	0.010	0.077	2.01	2.17	0.56	0.58	2.55	2.71
	jhw	0.012	0.065	1.93		0.63		2.26	
	ymn	0.006	0.129	2.51		0.64		3.15	
Naju	chh	0.016	0.053	0.50	0.76	0.96	0.89	0.91	1.41
	ymn	0.017	0.043	0.99		0.83		1.73	
Jinju	chh	0.022	0.029	2.51	2.78	0.60	0.48	3.08	3.40
	ymn	0.020	0.028	3.02		0.25		3.65	
Entire set				2.54		0.75		3.61	

Daegu, Gwangju, and Jinju) operated by the Korea Meteorological Administration (KMA) and the monitoring sites for bud-burst and full blooming dates of peach trees.

2.2. Full blooming date prediction models for peach trees

The developmental rate (DVR) has been described functions of temperature and the relationships between DVR and temperature have been assumed to be either linear (Behdani et al., 2008) or exponential (Aono, 1993; Aono and Omoto, 1990; Omoto and Aono, 1989; Ono et al., 1988). In this study, both linear (Eq. (1)) and exponential (Eq. (2)) models for the DVR model were used and compared for the six major sites and five cultivars. According to Sameshima and Iwakiri (1987), the developmental rate (DVR) can be defined by the reciprocal of the number of days required for flowering (hereinafter referred to as the required days). It is assumed that only the days when daily mean temperature is greater than and equal to be 5 °C contribute to the development of peach trees as National Academy of Agricultural Science (NAAS) proposed (NAAS, 1990). Based on this assumption, to calculate the DVR in Eqs. (1) and (2), we counted the number of days when daily mean temperature ≥5 °C as the required days from January 30 to the full blooming dates and took the reciprocal of the required days. This method for the calculation of the DVR has been used for studies by Moncur et al. (1989), NAAS (1990) and Yun et al. (2012). Once the DVRs for each day were calculated, the DVRs were summed until those sum reached 1.0 to determine the full blooming dates since the DVR_T Eqs. (1) and (2) means the rate of reaching the full blooming dates (NAAS, 1990; Yun et al., 2011; Yun et al., 2012).

$$DVR_T = A + B \times T \quad (1)$$

$$DVR_T = C \times e^{(D \times T)} \quad (2)$$

where T is the daily mean temperature (when T ≥ 5 °C) and A, B, C, and D are constants and coefficients. The REG procedure for Eq. (1) and NLIN procedure for Eq. (2) in SAS statistical software (The SAS system for Windows, 9.2, SAS Institute Inc., Cary, NC, USA) were used to fit

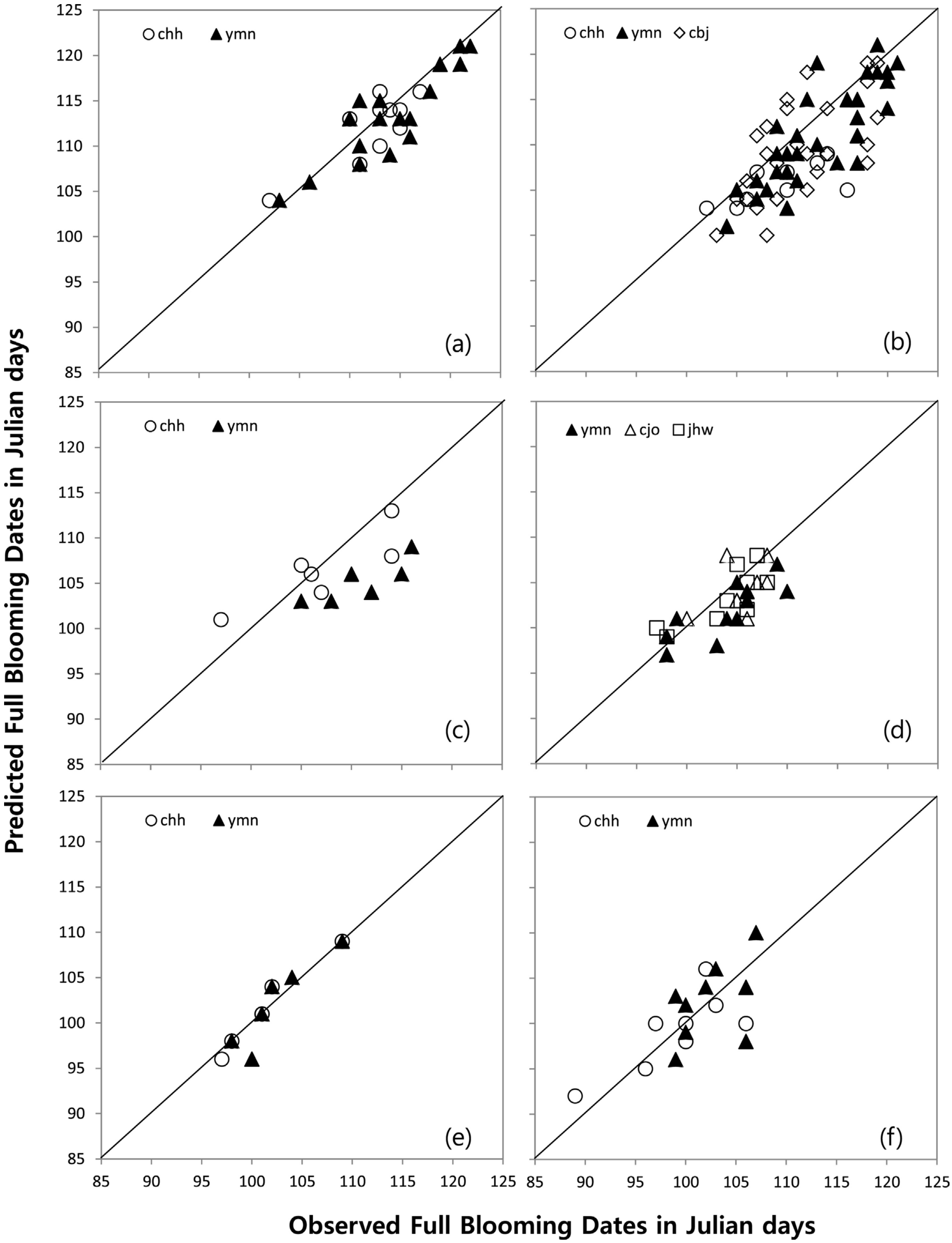

Fig. 2. Predicted and observed full blooming dates in Julian days at the Chuncheon (a), Suwon (b), Cheongwon (c), Cheongdo (d), Naju (e) and Jinju (f) sites, using the DVR model.

those parameters (A, B, C, and D) in Eqs. (1) and (2).

Two sequential dormancy models (chill day and new chill day models proposed by Cesaraccio et al., 2006) were applied for the prediction of full blooming dates of peach trees. More detailed information of the concept of the two sequential dormancy models can be found in Cesaraccio et al. (2004, 2005, 2006). There can be five cases depending on the relationships among daily minimum and maximum temperatures and threshold temperature (T_C). For these five cases, the equations of the accumulations of chill days (C_d) and anti-chill days (C_a) summarize in Table 2. The single triangle method and a modified single triangle method (i.e., an inverted triangle) were used to calculate C_d and C_a for chill day and new chill day models (i.e., degree day calculations), respectively. More detailed description can be found in Cesaraccio et al. (2004, 2006). The T_C and chilling requirement (C_R) for the observed bud-burst and full blooming dates were estimated with an iteration method. Based on literature review (e.g., Cesaraccio et al., 2004, 2005, 2006; Jung et al., 2005; Kim et al., 2013; Kuzmanova, 2015), we assumed the ranges of T_C and C_R ($5\,^{\circ}C \le T_C \le 10\,^{\circ}C$, $-70 \le C_R \le -150$). In the concept of the sequential dormancy models (Cesaraccio et al., 2004), rest is broken when $\Sigma|C_d| \ge |C_R|$ and quiescence is overcome when $\Sigma|C_a| \ge |C_R|$. An iteration method was used to determine the T_C and C_R values. First, the initial T_C and C_R values were assumed in the ranges T_C and C_R. These assumed values were used to calculate C_a and C_R by using the equations in Table 2. Bud-burst dates were estimated and compared with the observed bud-burst dates. Finally, the T_C and C_R were determined when Root Mean Square Error (RMSE) of the estimates against observed bud-burst dates was lowest. With those T_C and C_R, the heating requirement (H_R) values proposed by Jung et al. (2005) for each observed full blooming dates were calculated and averaged. The periods when both bud-burst and full blooming dates were observed were used to estimate the T_C, C_R, H_R values, while the periods with observations of only full blooming dates were used to validate the models.

The performance of the full blooming date prediction models was assessed with three goodness-of-fit measures such as the Mean Absolute Percentage Error (MAPE, Eq. (3)), R^2 (coefficient of determination), and Root Mean Square Error (RMSE, Eq. (4)).

$$\mathrm{MAPE}=\frac{100}{N}\sum_{i=1}^{n}\left|\frac{O_i-P_i}{O_i}\right| \tag{3}$$

$$\mathrm{RMSE}=\sqrt{\frac{\sum_{i=1}^{n}(O_i-P_i)^2}{N}} \tag{4}$$

where O_i is the observed value and P_i is the predicted value.

3. Results and discussion

3.1. DVR model

The required days varied with the range of 36.1 ('Cheonghong' at the Jinju site) to 44.5 days ('Youmyeong' at the Cheongdo site). Especially, the mean value of the required day of 'Youmyeong' at the Suwon site was approximately 39.5 days. This result is similar to the required day (40 days) of 'Youmyeong' reported by Yun et al. (2012). The required days for full blooming were fitted into both linear and exponential models and were compared. No significance at the 0.05 probability level was found in the linear models for most of the sites, while all of the exponential models showed significance at the 0.05 probability level. In addition, the R^2 values for the linear models were very low (less than 0.4). These results are different from those by Yun et al. (2012). Yun et al. (2012) reported that significance at the 0.05 probability level and high R^2 values (about 0.7) were found in both linear and exponential models. One possible explanation is that they selected 15 out of 30 observations to fit both linear and exponential models. For this study, only exponential models were used to further discuss. As shown in Table 3, the results showed that fitted constants and coefficients were different from locations and cultivars. The Leave-One-Out cross validation was conducted for this fitted parameters. Most of those were within the 95% confidence intervals (data not given). The fitted constants ranged from 0.002 ('Youmyeong' at the Cheongwon site) to 0.022 ('Cheonhong' at the Jinju site) and the fitted coefficients varied with the range of 0.028 ('Youmyeong' at the Jinju site) to 0.21 ('Youmyeong' at the Cheongwon site). Those constants and coefficients for 'Youmyeong' and 'Changbangjosaeng' at the Suwon site were (0.007, 0.138) and (0.08, 0.127), respectively. These values were slightly different from those by Yun et al. (2012) and NAAS (1990). These differences can be explained by considering the number of observed full blooming dates to fit the models. Yun et al. (2012) selected 15 out of 30 observations for the fitting and the observed period of NAAS (1990) was about half of that in this study.

Fig. 2 displays the predicted full blooming dates resulted from the DVR models. The full blooming dates at the Naju (Fig. 2e) and Jinju (Fig. 2f) sites were earlier than those at the Chuncheon (Fig. 2a) and Suwon (Fig. 2b) sites. The DVR models showed a tendency to under-predict the full blooming dates (i.e., earlier than the observed full blooming dates). Three measures of goodness-of-fit (MAPE, R^2, and

Table 4
Estimated parameters (T_C, C_R, and H_R) and goodness-of-fit measures for the Chill day models.

Site	Cultivar	T_C	C_R	H_R	MAPE (%)		R^2		RMSE (day)	
Chuncheon	chh	5.0	−100	244.0	1.69	1.91	0.72	0.79	2.51	2.96
	ymn	5.0	−110	245.0	2.04		0.80		3.19	
Suwon	cbj	5.0	−107	232.9	2.94	2.51	0.54	0.72	4.15	3.71
	chh	5.0	−107	240.1	1.82		0.85		2.31	
	ymn	6.0	−73	180.2	2.33		0.59		3.63	
Cheongwon	chh	5.0	−133	261.8	2.19	1.71	0.88	0.63	2.45	2.12
	ymn	7.0	−95	199.2	1.22		0.83		1.73	
Cheongdo	cjo	9.0	−73	137.2	2.69	2.11	0.44	0.54	3.92	3.08
	jhw	9.0	−73	134.0	2.36		0.42		3.23	
	ymn	5.2	−130	277.4	1.38		0.81		1.81	
Naju	chh	8.0	−71	149.6	2.44	1.94	0.73	0.57	3.08	2.69
	ymn	8.0	−74	150.0	1.51		0.59		2.30	
Jinju	chh	6.0	−123	215.7	1.99	2.36	0.80	0.64	2.24	2.82
	ymn	5.1	−148	271.0	2.70		0.26		3.25	
Entire set					2.22		0.80		3.22	

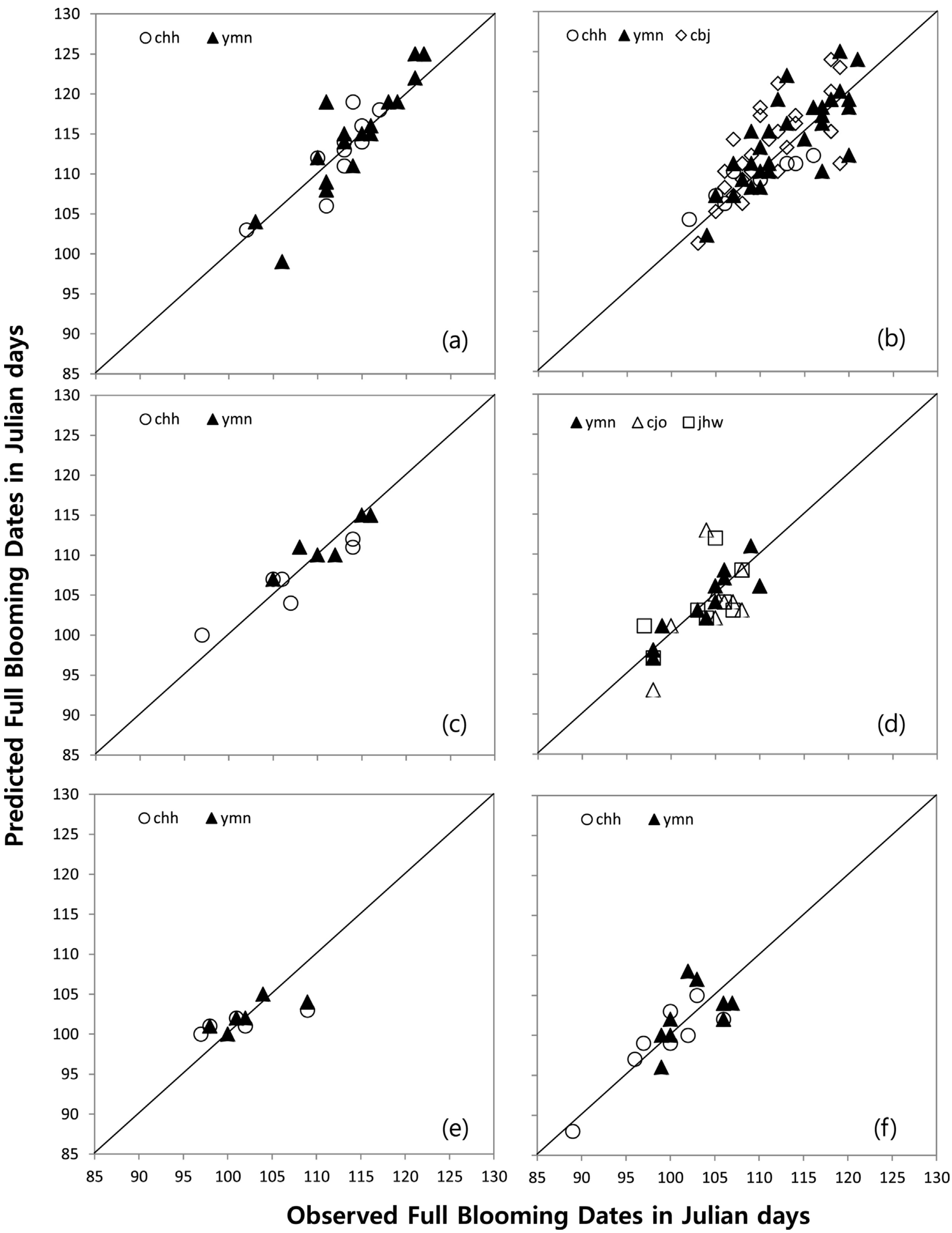

Fig. 3. Predicted and observed full blooming dates in Julian days at the Chuncheon (a), Suwon (b), Cheongwon (c), Cheongdo (d), Naju (e) and Jinju (f) sites, using the Chill day model.

RMSE) were used to evaluate the models and the results are presented in Table 3. The highest MAPE (5.2%) was found from the 'Youmyeong' cultivar at the Cheongwon site and the highest R^2 value was 0.96 for the 'Cheonhong' cultivar at the Naju site. The RMSE values varied with the range of 0.91 (the 'Cheonhong' cultivar at the Naju site) to 6.31 (the 'Youmyeong' cultivar at the Cheongwon site) days. The three measures for the entire dataset regardless of the site and cultivar were 2.54%, 0.75, and 3.61 day for MAPE, R^2, and RMSE, respectively. These results

Table 5
Estimated parameters (T_C, C_R, and H_R) and goodness-of-fit measures for the new chill day models.

Site	Cultivar	T_C	C_R	H_R	MAPE (%)		R^2		RMSE (day)	
Chuncheon	chh	5.0	−82	231.3	1.34	1.54	0.78	0.81	1.97	2.40
	ymn	5.2	−92	228.5	1.66		0.81		2.61	
Suwon	cbj	6.0	−81	186.6	3.01	2.38	0.56	0.79	4.18	3.52
	chh	5.9	−81	196.3	2.12		0.53		3.00	
	ymn	5.0	−93	210.2	1.91		0.74		2.99	
Cheongwon	chh	7.0	−82	176.2	1.87	1.69	0.95	0.68	2.16	2.20
	ymn	7.0	−87	186.1	1.51		0.67		2.24	
Cheongdo	cjo	5.0	−140	272.1	2.80	2.29	0.56	0.61	3.42	2.92
	jhw	5.0	−140	266.5	2.93		0.45		3.38	
	ymn	5.3	−131	263.2	1.30		0.83		1.78	
Naju	chh	5.1	−114	236.5	1.50	1.83	0.77	0.65	1.96	2.32
	ymn	5.1	−114	234.9	2.12		0.57		2.59	
Jinju	chh	7.0	−75	153.4	1.97	2.19	0.71	0.62	2.65	2.89
	ymn	6.0	−94	200.7	2.38		0.36		3.09	
Entire set					2.12		0.83		3.02	

are close to those by Yun et al. (2012) and are better than those by Kim et al. (2009) predicted the full blooming dates for the 'Changhowon' cultivar at the Suwon site, and they reported that the RMSE value was 7 days.

3.2. Sequential dormancy model

The sequential dormancy models, the chill day and new chill day models, were used for this study. Table 4 summarizes the estimates of T_C, C_R, and H_R for the chill day models. The estimates of T_C and C_R ranged from 5 to 9 °C and from −71 to −148, respectively, while the estimated H_R varied with the range of 134.0 and 277.4. These results showed similar results from Kim et al. (2009) and Hur and Ahn (2014). Kim et al. reported that the estimated T_C, C_R, and H_R values were 5.7 °C, −108, and 234.5, respectively. Similar values (T_C: 5 °C, C_R: −99 and H_R: 183.3) were reported by Hur and Ahn (2014).

For the development of the chill day and new chill day models, the periods with the observed bud-burst dates were used for training periods and the rest of collected periods were used for validation. The RMSE values for both periods were similar with the range of 2–5 days. The predicted full blooming dates using the chill day models were compared with the observed full blooming dates and the results are displayed in Fig. 3. Unlike the results by the DVR models, no apparent tendency was observed. The goodness-of-fit measures for the chill day models are summarizes in Table 4. The MAPE values ranged from 1.22 (the 'Youmyeong' cultivar at the Cheongwon site) to 2.94% (the 'Changbangjosaeng' cultivar at the Suwon site) and the RMSE values varied with the range of 1.73 (the 'Youmyeong' cultivar at the Cheongwon site) to 4.15 days (the 'Changbangjosaeng' cultivar at the Suwon site). The highest R^2 value (0.88 for the 'Cheonhong' cultivar) was found at the Cheongwon site. The MAPE, R^2, and RMSE values for the entire dataset were 2.22%, 0.80, and 3.22 days, respectively. These values showed that the chill day models better predicted the full blooming dates than the DVR models. This result is in substantial agreement with that of Kim et al. (2009). Kim et al. (2009) reported that a better performance of the chill day model was observed than that of the DVR model.

The estimated T_C, C_R, and H_R for the new chill day models are summarized in Table 5. The estimated T_C and C_R varied with the ranges of 5–7 °C and of −75 to −140, respectively. The estimated H_R ranged from 153.4 to 272.1. These ranges were slightly smaller than those by the chill day model. The RMSE values of both training and validation periods were similar to those for the chill day model. The results from the new chill day models are depicted in Fig. 4. No apparent tendency was found from the results by the new chill day models like those by the chill day models. It was found that the ranges of the goodness-of-fit measures for the chill day models were similar to those for the new chill day models. The ranges of MAPE and RMSE were from 1.34 (the 'Youmyeong' cultivar at the Cheongdo site) to 3.01% (the 'Changbang-josaeng' cultivar at the Suwon) and from 1.78 (the 'Youmyeong' cultivar at the Cheongdo site) to 4.18 days (the 'Changbangjosaeng' cultivar at the Suwon), respectively. Like the chill day models, the highest R^2 value was found from the 'Cheonhong 'cultivar at the Cheongwon site, although the value (0.95) was higher than that by the chill day model. For the new chill day models, those values for the entire dataset (2.12%, 0.83, and 3.02 day for MAPE, R^2, RMSE, respectively) were slightly better than those for the chill day models. This result is in good agreement with that of Cesaraccio et al. (2006). They found that the performance of the new chill day model for some fruit tree crops was slightly higher than that of the chill day model.

As shown in Tables 3–5, parameters and performances of each model were slightly different from the sites and cultivars. This result leads us to believe that the prediction model for the full blooming dates of peach trees can reflect the local and cultivar characteristics to better predict the full blooming dates. T_C may reflect site characteristics and C_R can be different between species (Cesaraccio et al., 2004). However, it should be noted that the number of observations for the model development were different from the sites and cultivars and this could contribute to the differences of the parameters and performances. It is recommended that the models should be improved through increases in the number of observations for the cultivars at each site in the future.

4. Conclusions

In this study, we attempted to develop the prediction models of full blooming dates for the five peach cultivars at the six major peach

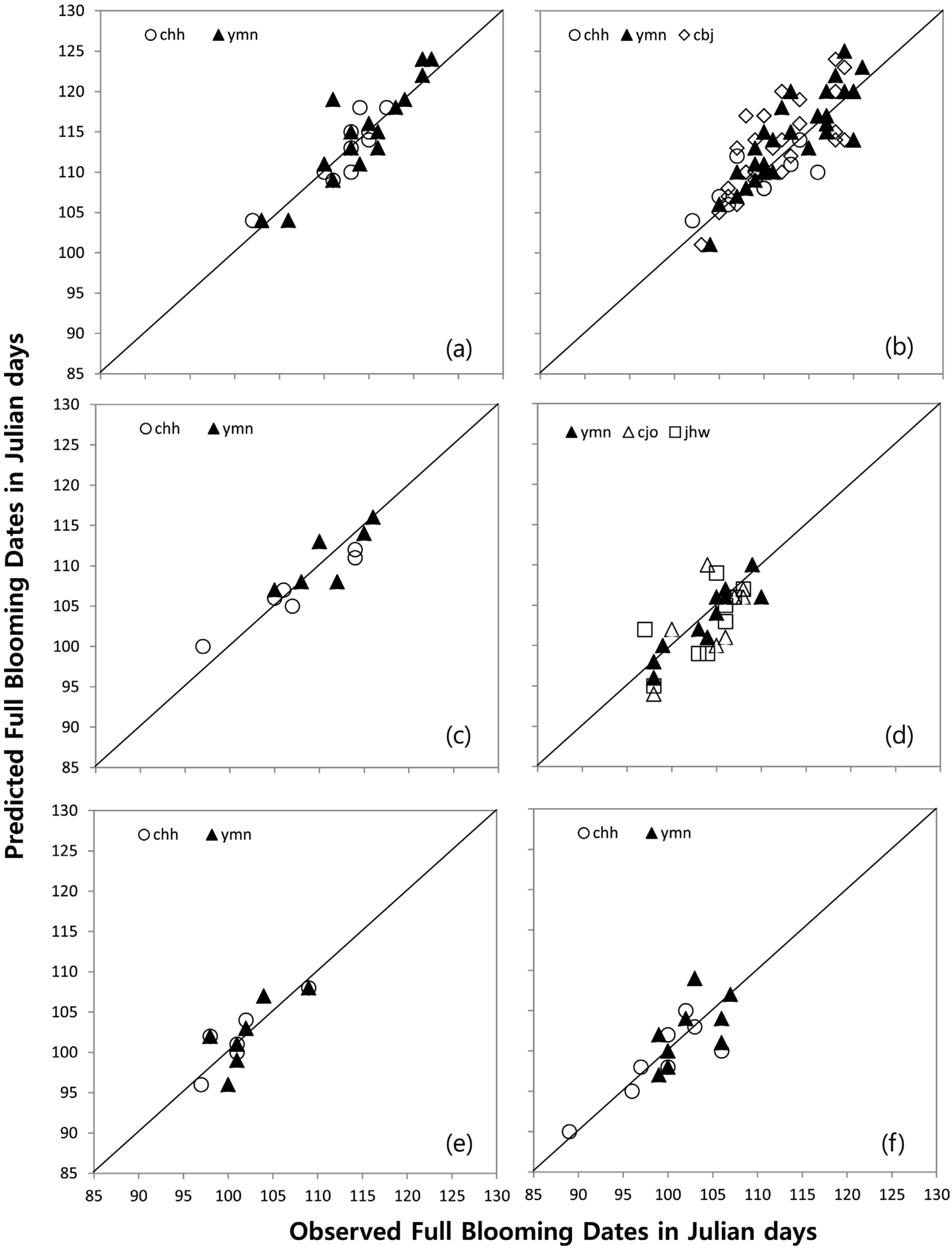

Fig. 4. Predicted and observed full blooming dates in Julian days at the Chuncheon (a), Suwon (b), Cheongwon (c), Cheongdo (d), Naju (e) and Jinju (f) sites, using the New Chill day model.

cultivation sites using the DVR model, chill day model and new chill day models. The DVR models tended to underpredict the full blooming dates, while no apparent tendencies were found from the results by the chill day and new chill day models (Figs. 2–4). The new chill day models showed better performances than the other two models. The estimated parameters and performances for those models were slightly different from the sites and cultivars (Tables 3–5). These findings imply that some models are better for certain cultivars or sites. However, since one possible explanation is that the numbers of observations are different from the sites and cultivars, a further study is recommended on the model improvement through increases in the numbers of the observations for the sites and cultivars.

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