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ORIGINAL ARTICLE / ORIGINALBEITRAG

Pistachio Production Management in Iran by Rest-breaking Treatment and Comparison of Dynamic vs Chill Hour Model for Chill Accumulation

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Abstract
Shortage of winter chill has reduced pistachio (*Pistacia vera* L.) fruit yield and quality from 2015 to 2018 in Iran. In this study accumulated chilling was determined by the chill hour (CH) and the dynamic (DM) model in five regions near Shahrebabak County, Kerman Province, Iran, for dormant season 2017–2018. The CH model has been routinely used in Iran for reporting chilling accumulation for pistachios. This study suggested that the DM better differentiated regional chill accumulations, the impact of chilling on phenological indices of growth and production between cultivars 'Owhadi' and 'Akbari', with and without rest-breaking (RB) treatments of Volk dormant oil. Volk oil treatment significantly improved vegetative and reproductive development, offset lack of chilling effects on pollination and nut filling, and may have advanced budbreak in some instances.

Keywords Dormancy · Chilling requirement · CH model · DM model · Pistachios

Pistazienanbau im Iran: Brechung der Winterruhe durch Ölapplikation und Vergleich zweier Modelle zur Ermittlung der Kältestunden (Dynamisches Modell, Chill Hour Modell)

Schlüsselwörter Kältebedürfnis · Vollruhe · Dormanz · Chill Hour Modell · Dynamisches Modell · Pistazien

Introduction

In some pistachio production regions with mild winters and insufficient chill, vegetative and reproductive growth has been limited by cumulative chilling (Lang 1987; Campoy et al. 2011; Viti et al. 2010). Determining the chill requirement for deciduous fruit trees to resume normal flowering and cropping (Campoy et al. 2011) and how best to measure that requirement for a given region, species and cultivar is essential where chilling is limiting (Fishman et al. 1987). Arora et al. (2003) described the mechanism of bud dormancy and dormancy release in deciduous fruit trees. High winter temperatures are a main physiological problem in subtropical fruits (Byrne 2005). Lack of chilling in mild winter regions results in uneven and abnormal patterns of budbreak and flower bud abscission (Crossa-Raynaud 1955; Legave et al. 1982; Erez 1987; Erez and Couvillon 1987; Erez 1999; Ben Mimoun 2008; Viti et al. 2010; Campoy et al. 2012). Pistachio has a specific genetic chilling requirement to break dormancy and start normal growth (Alonso et al. 2005; Egea et al. 2003; Ruiz et al. 2007; Mahmoudi Meimand and Ghanbari Odivi 2014). Uneven budbreak due to lack of sufficient winter chilling has been reported in many of Iran pistachio regions (Rahemi and Asghari 2004). Global warming indicates trends for warmer winters and greater impacts on deciduous tree crops as a result (Baldocchi and Wong 2008; Zhang and Taylor 2011), including pistachio (Rahemi and Asghari 2004). A range of 600–1260 chilling hours (CH) as a chilling requirement has been reported for different pistachio cultivars (Mahmoudi Meimand and Ghanbari Odivi 2014). Among Iranian pistachio cultivars, 'Kale_Ghochi' is the lowest in chill requirement and 'Akbari' is the highest (Mahmoudi Meimand and Ghanbari Odivi 2014). The CH model doesn't address chill cancelation due to high temperatures during

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the dormant season, nor do various models that are adequate for continental conditions where chilling isn't lacking (Dennis 2003), such as the Utah Model (Richardson et al. 1974; Dennis 2003), 'positive' chill units (Linsley-Noakes et al. 1995), and 'weighted' chill units (Powell 1997). The Dynamic Model (Fishman et al. 1987; Erez et al. 1988) was developed to address chill cancelation as well as accumulation. Since global warming models estimate decreasing winter chill between 30 and 60% by the end of the 21st century, overcoming lack of chilling may require rest-breaking (RB) treatments (Jackson and Bepete 1995; Mohamed 2008; Campoy et al. 2010; Theron et al. 2011; Seif El-Yazal and Rady 2012). Previous RB work in pistachio has tested oil-DNOC, Armobreak, hydrogen cyanamide (Dormex), potassium nitrate and Volk oil (Procopiou 1973; Kuden et al. 1995; Beede and Ferguson 2002; Rahemi and Asghari 2004). Volk oil may be an effective, cheap and readily available agent for advancing floral and vegetative budbreak, improved kernel filling (Beede and Ferguson 2002), increased bloom, lateral budbreak, higher female flower numbers and improved kernel weight (Rahemi and Asghari 2004) and improved synchronization of male and female flowers (Rahemi and Asghari 2004). As pistachio is very important in Iran, this study compared the DM to CH model, chill accumulation effects on pistachio budbreak and reproduction and RB with Volk oil to overcome lack of adequate chill.

Material and Methods

Chill accumulation was measured hourly during the dormant season of the years 2016 and 2017 (10-23-2016, 2-04-2017) in five localities in Shahrebabak County, Kerman Province, Iran (30.1172° N, 55.1210° E; Robat West, Robat East, Dasht-E-Khabr, Estabragh and Mehrabad, Fig. 1). Effective chilling was calculated counting the hours in which the temperature remained ≤7.2 and >0 °C as per the DM, recorded by data logger and chill portions calculated using the template Excel file from UC Davis (https://ucanr.edu/sites/fruittree/How-to_Guides/Dynamic_Model_-_Chill_Accumulation/; courtesy of Amnon Erez, author). For purposes of these studies, the test orchards were considered similar for soil and water conditions, trees were of the same age (15 years old), tree size, and cultural practices. The test cultivars were 'Owhadi' and 'Akbari', both of medium to high chilling requirement, all in an 'on year' for bloom. RB was Volk oil in concentration of 50 liter/1000 l H_2O, applied on February 14, 2017, in the region. The experimental design was completely randomized (CRD) with four treatments (2 RB × 2 cultivars), 8 trees per replicate. Initial and final fruit set, blanking nuts, half kernel nuts, and malformed nuts, as well as number of shelled nuts per ounce, fresh and dry weight per kg per acer were determined for each replicate. All flowers counted per tree in each replicate. Leaf and floral bud numbers per shoot and their ratio in new shoots, shoot length and percent floral bud drop from the one-year-old branches were measured. Correlations by region (chill accumulation) and RB treatment for each chill model were calculated by Pearson correlation coefficients. Statistical analysis was conducted using SAS software (9.2) factorial design, and means were compared by LSD ($P \leq 0.01$ and 0.05).

Results

Outputs of Dynamic Model (DM) and Chill Hours (CH) Model

A comparison of the chill portion (CP) accumulation by DM for studied regions based dynamic model (DM) was stated through the experimental period (Fig. 2). The first and most practical result of the experiment based on the output of the models was the difference between different regions, however close together. The results indicated that, based on the dynamic model, the chill portion (CP) accumulation starting in all studied regions was the same and

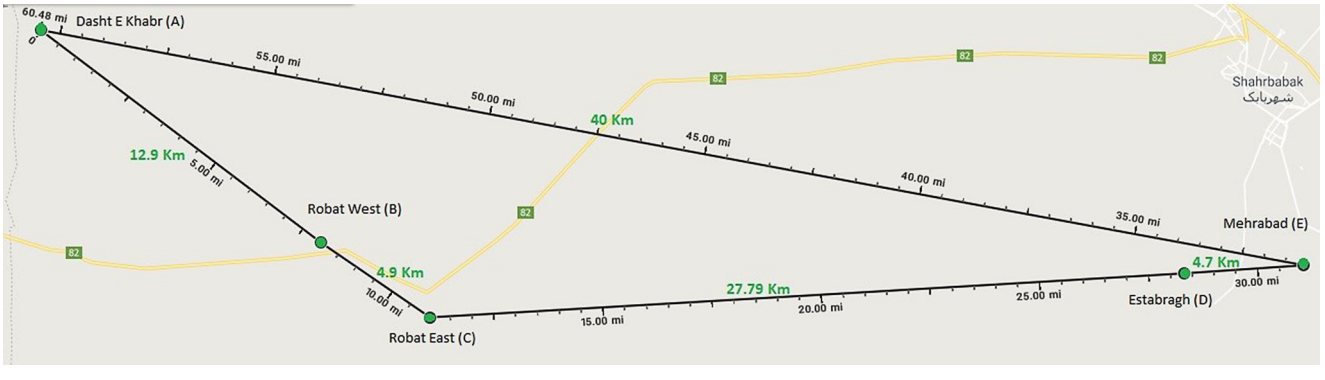

Fig. 1 Position of five climatically localities in Shahrebabak (30.1172° N, 55.1210° E) city (Robat west part, Robat East part, Dasht-E-Khabr, Estabragh and Mehrabad) and the distance between them

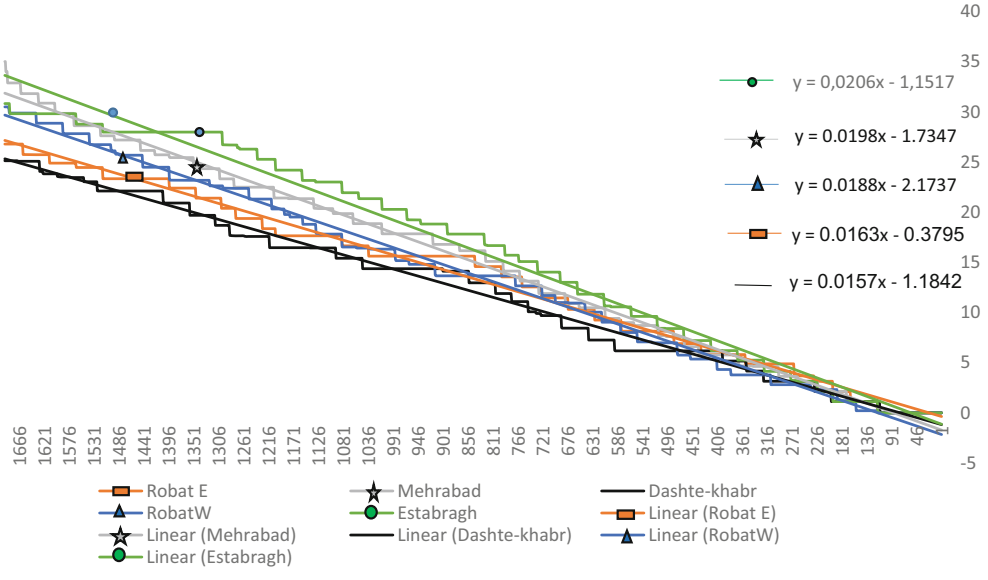

Fig. 2 Chill portions (CP) accumulated in the all studied regions based on the dynamic model (CPA), through experimental period

was started approximately from November 18, but in the west area of Robat was later than others, where the chill portion began to be accumulated from November 20. According to our findings, the result of the dynamic model also showed a greater accumulation of the chill portion in Mehr Abad (35% CP), but the slope of the curve of accumulated chill for Mehr Abad was 3.8% shallower than that of the curve for Estabragh region (Fig. 2, Table 5). The slope of the curve of accumulated chill for Estabragh region was steepest than all regions (Fig. 2). The minimum slope of the curve of accumulated chill and the minimum accumulation of the chill portion (CP) were observed for Dashte Khabr region. Based on the model of chill hours (CH), the maximum CH was observed for Robat (W) region (CH = 571) and the minimum was related to Robat (E) (CH = 445). At the end of the period, the accumulated CP in Mehr Abad was 0.28% higher than the accumulated chill portion in Dasht-e Khabr region (Fig. 2, Table 5).

Table 1 Reproductive growth parameters of pistachio 'Owhadi' variety, affected by different cumulated chilling levels, in Shahrebabak different pistachio production regions includes Mehrabad, Estabragh, Robat (W), Robat (E) and Dasht-E-Khabr, calculated by hourly temperatures recorded per each site, through 2017–2018; plants treated by Volk oil rest-breaking agent versus control ones

Rest-breaking agent	Regions	Initial fruit set (%)	Final fruit set (%)	Blanking (%)	Half kernel (%)	Malformed fruit (%)	Ounces	Fresh weight (kg/acer)	Dry weight (kg/acer)
Volk oil treatment	Mehrabad	52.7 a	44.6 a	6.42 f	2.02 b	0.97 d	32.25 e	3105 a	1273.65 a
	Estabragh	51.2 a	43.4 ab	6.62 f	2.25 b	0.95 d	32.5 de	3234.9 a	1237.30 a
	Robat (W)	41.7 bc	40 bc	6.75 def	2.70 a	1.90 c	32.25 e	2779.5 b	1056.33 b
	Robat (E)	42.7 b	39.8 bc	6.65 ef	2.65 a	1.20 d	32.25 e	2648.6 b	995 b
	Khabr	40.7 bc	37 c	8.47 cd	2.85 a	1.95 c	33.5 cd	2666.2 b	1003.75 b
Control	Mehrabad	41.2 bc	36.7 c	8.37 cde	2.85 a	2.15 abc	34.5 bc	1484.2 c	558.24 c
	Estabragh	40.7 bc	37.6 c	9.05 bc	2.87 a	2.05 bc	35.25 ab	1494.8 c	545.43 c
	Robat (W)	40.2 bc	27.6 d	10.2 ab	2.82 a	2.20 abc	35.25 ab	1110.2 d	409.50 d
	Robat (E)	39.5 bc	27 d	11.37 a	2.85 a	2.45 a	35.75 a	1173.4 d	389.04 d
	Khabr	37.7 c	25.5 d	11.3 a	2.85 a	2.30 ab	34.75 ab	1107.4 d	367.78 d
Analysis of variance									
Regions (A)		**	**	**	**	**	*n.s*	**	**
Volk (B)		**	**	**	**	**	**	**	**
A * B		*	**	**	**	**	**	**	**

Means followed by the same letters are not significantly different ($P \geq 0.01, 0.05$)
Volk oil in concentration of 50 liter/1000 l H_2O, applied on February 14, 2017, in all regions

Table 2 Reproductive growth parameters of pistachio 'Akbari' variety, affected by different cumulated chilling levels, in Shahrebabak different pistachio production regions includes Mehrabad, Estabragh, Robat (W), Robat (E) and Dasht-E-Khabr, calculated by hourly temperatures recorded per each site, trough 2017–2018; plants treated by Volk oil rest-breaking agent versus control ones

Rest-breaking agent	Regions	Initial Fruit set (%)	Final fruit set (%)	Blanking (%)	Half kernel (%)	Malformed fruit (%)	Ounces	Fruit fresh (w) (kg/acer)	Fruit dry (w) (kg/acer)
Volk oil treatment	Mehrabad	57.25 a	51.90 a	7.32 c	2.07 ab	0.55 d	22.77 d	1714.8 a	721.27 a
	Estabragh	56 a	50.10 ab	7.57 c	1.95 b	0.60 cd	22.75 d	1653.7 a	721.64 a
	Robat (W)	54.50 a	46.59 b	7.80 c	2.10 ab	0.52 d	23.32 bcd	1664.8 a	690.94 a
	Robat (E)	54 a	48.07 ab	7.82 c	2.20 ab	0.60 cd	23.05 cd	1611.3 a	678.87 a
	Khabr	41.75 b	47.80 ab	9.32 b	2.25 a	0.67 abc	23.32 bcd	1576 a	671.15 a
Control	Mehrabad	22.75 c	14.20 c	9.4 b	2.25 a	0.72 ab	23.92 ab	508.01 b	200.98 b
	Estabragh	22.50 c	12.51 cd	10.05 ab	2.22 a	0.65 c	23.7 abc	466 bc	170.97 bc
	Robat (W)	21.50 c	27.6 cd	9.55 b	2.25 a	0.75 a	23.3 abcd	465.5 bc	174.34 bc
	Robat (E)	21.50 c	12.29 cd	10.7 a	2.27 a	0.75 a	24.12 a	444.7 bc	160.81 bc
	Khabr	17.25 c	9.05 d	10.7 a	2.25 a	0.75 a	24.12 a	334.5 c	117.93 c
Analysis of variance									
Regions (A)		**	*n*.s	**	*n*.s	*	*n*.s	*n*.s	*n*.s
Volk (B)		**	**	**	*	**	**	**	**
A * B		**	**	**	*n*.s	**	**	**	**

Means followed by the same letters are not significantly different ($P \geq 0.01, 0.05$)
Volk oil in concentration of 50 liter/1000 l H_2O, applied on February 14, 2017, in all regions

Reproductive Growth

Fruit Set

According to our results, the initial fruit set of pistachio 'Owhadi' and 'Akbari' was affected by the different levels of accumulated the chill portion, Volk treatment and their interaction effects in different regions of pistachio production in Shahrbabak ($p \leq 0.01$ and 0.05) (Table 1). The highest number of initial fruit set was found by Volk treatment in Mehr Abad region (52.7%), followed by Estabragh (51.2%) for 'Owhadi' cultivar with no significant difference (Table 1). There was no significant difference between other remained regions treated by Volk with together and also with control group (without the application of Volk oil), except Dasht-e Khabr region (Table 1). The minimum value for 'Owhadi' fruit set (37.7%) was observed in Dasht-e Khabr without Volk. For 'Akbari' cultivar, the highest number of initial fruit set was found by Volk treatment in Mehr Abad region (57.25%), followed by Estabragh (56%) with no significant difference (Table 2). For Dasht-e Khabr, Volk oil treatment could not increase the initial fruit set for 'Akbari' cultivar like other regions and there was significant difference between them while treated by Volk (Table 2). Our results showed a significant decrease in the initial fruit set for 'Akbari' cultivar (control) (without the application of Volk oil) in all regions. The minimum value for 'Akbari' fruit set (17.25%) was observed in Dasht-e Khabr without Volk. The final fruit set also had a similar trend to the initial set with little difference. For 'Owhadi' cultivar, the highest number of final fruit set was related to Mehr Abad region, treated by Volk (44.6%), and followed by Estabragh (43.4%) with no significant difference (Table 1). The highest final fruit set for 'Akbari' was observed for Mehr Abad region, treated by Volk (51.90%). Totally, in Mehr Abad region, 90.6% of fruit set initially were converted to next growth stage for 'Akbari' trees treated with Volk, and for 'Owhadi', this value was equal to 84.6%. The conversion coefficient of initial fruit set to final fruit set in Dasht-e Khabr region (control) (without Volk treatment) for 'Akbari' was 52.4% and for 'Owhadi' was 67.6%. This means that 'Akbari' cultivar showed better reaction to Volk treatment and the lowest conversion factor in state of without the application of Volk oil in leak of winter chill condition.

Blanking Nut Fruits

Our results demonstrated that the level of accumulated the chill portion, Volk treatment and their interaction effects had significant effects on pistachio nut blanking for both 'Owhadi' and 'Akbari' cultivars (Tables 1 and 2). Blanking was more in the control group rather than Volk treatment for both 'Owhadi' and 'Akbari' cultivars. The highest nut blanking percent (11.37%) was related to the control group in the east area of Robat for 'Owhadi', followed by Dasht-e Khabr region (11.3%) with no significant difference (Table 1). The minimum value for nut blanking was obtained by Volk treatment in Mehr Abad region (6.42%). According to our results, by enhancing vegetative growth of trees, Volk oil treatment decreased the effects of high

temperature on pollination and fertilization, and also induced more homogamy with pistachio male trees, thereby decreasing blank nuts. Pistachio 'Akbari' cultivar showed the same trend (Table 2).

Half Kernel and Malformed Fruit

The minimum numbers of half kernel nuts were obtained in Mehr Abad (2.02%) and Estabragh (2.25%) regions and Volk treatment for 'Owhadi' cultivar. There was no significant difference between other treatments (Table 1). For 'Akbari' cultivar, the minimum number of half kernel nuts were obtained in Estabragh region (1.95%), treated with Volk. There was no significant difference between other treatments (Table 2). The number of malformed fruits was also affected by winter chill accumulation and Volk treatment. The minimum numbers of malformed fruits were observed in Mehr Abad (0.97%), Estabragh (0.95%) and the east area of Robat (1.20%), treated by Volk, with no significant difference with 'Owhadi' cultivar. For 'Akbari' cultivar, the number of malformed fruits followed a trend similar to 'Owhadi', and Volk oil treatment decreased the number of malformed fruits (Table 2). Based on the results, the total number of malformed fruits for 'Owhadi' cultivar was more than 'Akbari' one at all experimental levels.

Number of Pistachio Nuts per Ounce

The results reported in Table 1 proved that, by increasing winter chill accumulation based on the dynamic model, the number of pistachio ounces increased. According to the results, the minimum value for the number of pistachios per ounce for 'Owhadi' cultivar was related to Estabragh (32.5) and Mehr Abad (22.77) for 'Akbari' cultivar. These results demonstrated that more chill accumulation based on the dynamic model increased the size of nut fruit and induced better fruit growth and development (Table 2). Volk oil treatment increased the size of fruits in all experimental regions, but this increase was not observed for 'Owhadi' cultivar in Dasht-e Khabr. For 'Akbari' cultivar, the application of Volk oil treatment could not improve the size of fruits in Dasht-e Khabr and the east and west regions of Robat, which could be referred to the amount of chill accumulated before breaking agent treatment.

Fruit Fresh and Dry Weight (Kg/acer)

Fruit fresh and dry weight (kg/acer) was affected by winter chill accumulation, Volk oil and their interaction effects, significantly for 'Owhadi' cultivar ($p > 0.01$), but there was not significant difference between different regions and winter chill accumulation for 'Akbari' cultivar (Tables 1 and 2). For 'Owhadi', the highest fresh weight (3234.9 kg/acer) was observed for Estabragh region and for dry weight, Mehr Abad (1273.65 kg/acer) was in the first place (Table 1). The conversion coefficients of fresh weight to dry weight for 'Owhadi' cultivar in Mehr Abad and Estabragh were equal to 2.47 and 2.61, respectively. For another cultivar, the maximum fresh weight (1714.8 kg/acer) was observed for Mehr Abad region, and the maximum dry weight (721.64 kg/acer) was related to Estabragh (Table 2). The conversion coefficients of fresh weight to dry weight for 'Akbari' cultivar in Mehr Abad and Estabragh were equal to 2.37 and 2.29, respectively. Volk oil treatment increased both fresh and dry weights in two studied cultivars. The minimum amount of fresh and dry weight (kg) for two cultivars was obtained in Dasht-e Khabr for the control group (Tables 1 and 2). For 'Owhadi' cultivar, the application of Volk oil treatment also could not improve the fresh and dry weights in Dasht-e Khabr, and the east and west regions of Robat such as others, which could be referred to the amount of chill accumulated before breaking agent treatment.

Pistachio Vegetative Growth Parameters

Leafy Bud Number, Floral Bud Number and Leafy to Flower Bud Ratio

The results showed that leafy bud of pistachio 'Owhadi' cultivar was affected by winter chill accumulation, Volk oil application and their interaction effects ($p \leq 0.01, 0.05$), but for 'Akbari' cultivar, there was not any significant difference between different treatments (Table 3). The number of floral buds was significantly affected by different treatments for both studied cultivars ($p \leq 0.01, 0.05$). The ratio of leafy to floral bud was not affected by winter chill accumulation for 'Owhadi' cultivar, but Volk treatment and their interaction effects were significantly different (Table 3). For 'Akbari' cultivar, the ratio of leafy to floral bud was significantly affected by winter chill accumulation, Volk oil and their interaction effects ($p \leq 0.01, 0.05$). For 'Owhadi' cultivar, the maximum value for leafy bud number observed for Dasht-e Khabr, control treatment. Thus, the results showed that, by lack of chilling in mild winter regions based on the dynamic model, the number of leafy buds increased (Table 3). Similar results were seen in 'Akbari' cultivar with no significant difference (Table 4). Beside this, floral buds showed the reverse results and the regions with more chill accumulation based on the dynamic model showed more floral bud number (Tables 3 and 4). Volk oil treatment significantly increased floral bud number for both studied cultivars (Tables 3 and 4). the application of Volk oil treatment could not increase this parameter in Dasht-e Khabr.

Table 3 Vegetative growth parameters of pistachio 'Owhadi' variety, affected by different cumulated chilling levels, in Shahrebabak different pistachio production regions includes Mehrabad, Estabragh, Robat (W), Robat (E) and Dasht-E-Khabr, calculated by hourly temperatures recorded per each site, trough 2017–2018; plants treated by Volk oil rest breaking agent versus control ones

Rest-breaking agent	Regions	Leafy bud (No)	Floral bud (No)	Leafy bud to floral bud	Shoot length (cm)	Flower bud abscission
Volk oil treatment	Mehrabad	3.5 c	5.5 ab	0.63 c	23.75 ab	0 a
	Estabragh	3.25 c	5.75 a	0.57 c	23.50 ab	0 a
	Robat (W)	4 c	4.75 ab	0.82 c	23.75 ab	0 a
	Robat (E)	3.5 c	5.25 ab	0.66 c	24.25 a	4 a
	Khabr	4 c	4.5 b	0.88 c	24 a	4 a
Control	Mehrabad	6 b	2 c	3.54 b	21.50 bc	0 a
	Estabragh	5.5 b	1.75 cd	3.5 b	22.25 ab	4 a
	Robat (W)	6.25 ab	2 c	3.62 b	21.50 bc	8 a
	Robat (E)	6.5 ab	1 cd	5.75 a	19.75 cd	9 a
	Khabr	7.25 a	0.75 d	6.25 a	18 d	9 a
Analysis of variance						
Regions (A)		*	*	*n*.s	*n*.s	*n*.s
Volk (B)		**	**	**	**	*n*.s
A * B		**	**	**	**	*n*.s

Means followed by the same letters are not significantly different ($P \geq 0.01, 0.05$)
Volk oil in concentration of 50 liter/1000 l H_2O, applied on February 14, 2017, in all regions

Table 4 Vegetative growth parameters of pistachio 'Akbari' variety, affected by different cumulated chilling levels, in Shahrebabak different pistachio production regions includes Mehrabad, Estabragh, Robat (W), Robat (E) and Dasht-E-Khabr, calculated by hourly temperatures recorded per each site, trough 2017–2018; plants treated by Volk oil rest breaking agent versus control ones

Rest-breaking agent	Regions	Leafy bud (No)	Floral bud (No)	Leafy bud to floral bud	Shoot length (cm)	Flower bud abscission (%)
Volk oil treatment	Mehrabad	4.5 a	6.5 a	0.70 cd	27.75 a	4 c
	Estabragh	4.75 a	6.75 a	0.67 d	29 a	4 c
	Robat (W)	4.25 a	6.5 ab	0.70 cd	27.75 a	9 bc
	Robat (E)	4.5 a	5.74 ab	0.80 cd	27.25 ab	5 c
	Khabr	4.5 a	5 bcd	0.90 bcd	27.25 ab	21.25 a
Control	Mehrabad	4.75 a	5.25 bc	0.90 bcd	25.25 bc	17 ab
	Estabragh	4.75 a	5 bcd	0.97 bc	24.25 c	21.5 a
	Robat (W)	4.75 a	5 bcd	0.97 bc	24.25 c	25 a
	Robat (E)	4.75 a	4.25 cd	1.16 ab	24.75 c	21.5 a
	Khabr	5 a	4 d	1.27 a	23.75 c	25.5 a
Analysis of variance						
Regions (A)		*n*.s	**	*	*n*.s	*n*.s
Volk (B)		*n*.s	**	**	*	**
A * B		*n*.s	**	**	**	**

Means followed by the same letters are not significantly different ($P \geq 0.01, 0.05$)
Volk oil in concentration of 50 liter/1000 l H_2O, applied on February 14, 2017, in all regions

Shoot Length (cm)

Based on our findings, shoot length was significantly affected by Volk treatment ($p \leq 0.01$), but the amount of chill accumulation in different areas had no significant difference in shoot length for both studied cultivars (Tables 3 and 4). The minimum value for shoot length was related to the control treatment, but the control treatment in Dasht-e Khabr had the minimum value of shoot length for 'Owhadi' and 'Akbari' cultivars (Tables 3 and 4). By increasing winter chilling accumulation, shoot length improved in the control treatment, and the control treatment in Mehr Abad (25.25) showed more shoot length than other control treatments (Tables 3 and 4).

Abscission Percentage of Floral Buds

It was revealed that floral bud abscission just in bud swelling stage and before anthesis was not affected by the treatment for 'Owhadi' cultivar (Table 3). For 'Akbari', different re-

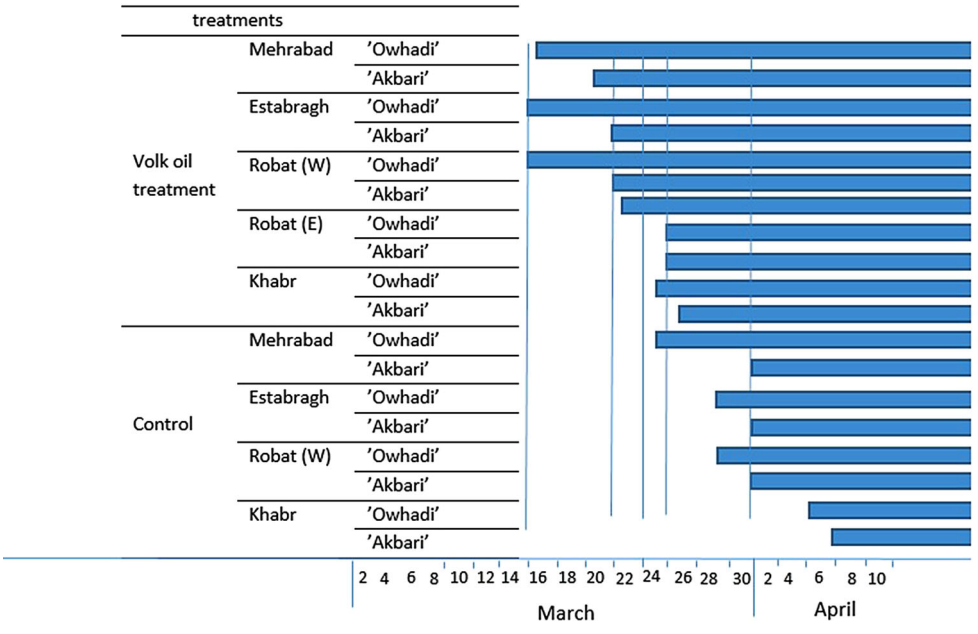

Fig. 3 Swollen bud or starting growth of pistachio 'Owhadi' and 'Akbari' variety, affected by different cumulated chilling levels, in Shahrebabak different pistachio production regions includes Mehrabad, Estabragh, Robat (W), Robat (E) and Dasht-E-Khabr. plants treated by Volk oil rest-breaking agent versus control ones

gions or winter chilling accumulation had no significant effect on floral bud abscission, but there was significant difference between Volk treatment and their interaction effects (Table 4). For 'Akbari' cultivar, the minimum amount of this parameter was observed for the trees treated with Volk oil (Table 4). The control treatment on Dasht-e Khabr had the maximum value for the abscission percentage of floral buds. For 'Owhadi' cultivar, Volk oil applicant also could not decrease floral bud abscission in Dasht-e Khabr region, which could be referred to the amount of chill accumulated before breaking agent treatment.

Swollen Bud Stage and Starting Growth

The results (Fig. 3) showed that swollen bud stage and starting growth for 'Owhadi' treated with Volk has been occurred in March 16–25 and for 'Akbari' cultivar, this has been occurred in March 20–27 in different experimental regions (Fig. 3). Findings showed that swollen bud stage and starting growth for 'Owhadi' control has been occurred in March 23–April 4 and for 'Akbari' cultivar, this has been occurred in March 30–April 6 in different experimental regions (Fig. 3). According to the results, Dasht-e Khabr showed the most delay for starting growth in both control and Volk-treated trees. Starting growth for 'Akbari' cultivar in the control treatment was the same in all different regions (Fig. 3). Starting growth for 'Owhadi' control in Estabragh and the west area of Robat was the same, but for the control group in Mehr Abad, it has been occurred earlier (Fig. 3). For 'Owhadi' and 'Akbari' cultivars treated with Volk, starting growth were the same in the west Robat and Estabragh, but for the control group in Mehr Abad, it has been occurred earlier for both cultivars (Fig. 3).

Correlation between Reproductive Growth Parameter and Chilling Models

Pearson correlation coefficients of some reproductive growth parameters of pistachio 'Owhadi' and 'Akbari' cultivar with dynamic and chill hour model outputs were calculated in different regions of pistachio production. For 'Owhadi' cultivar, the initial fruit set was positively and significantly correlated with dynamic and chill hour models (Table 5). A correlation coefficient between the initial fruit set and dynamic model was equal to 0.97** and a correlation coefficient between the initial fruit set and chill hour model was equal to 0.88*. There was a strong positive correlation between the final fruit set and the dynamic model (0.88*), but there was no correlation (non-significant) between the final fruit set and chill hour model ($0.22^{n.s}$) (Table 5). The number of blank fruits had a significant negative correlation with the dynamic model (–0.96*), but no correlation with the chill hour model ($-0.48^{n.s}$). Significant negative associations were found between the half kernel and dynamic model (–0.93*), but no correlation with the chill hour model ($-0.29^{n.s}$). The study of correlation coefficient of malformed fruits revealed that this trait was not significantly correlated with the dynamic model ($-0.73^{n.s}$), nor the chill hour model ($-0.06^{n.s}$), but correlation coefficients with the dynamic model was more than the chill hour model (Table 5). There was a highly significant negative correlation between the number of pistachio fruit per ounce and the dynamic model (–0.98**), but there was not a significant

Table 5 Pearson correlation coefficients of some reproductive growth parameters of pistachio 'Owhadi' variety with dynamic and chill hour model outputs, calculated in Shahrebabak different pistachio production regions includes Mehrabad, Estabragh, Robat (W), Robat (E) and Dasht-E-Khabr based hourly temperatures recorded by Data logger per each site, trough 2017–2018

Rest-breaking agent	Regions	Initial fruit set (%)	Final fruit set (%)	Blanking (%)	Half seed (%)	Malformed fruit (%)	Ounces	Fruit fresh (kg/acer)	Fruit dry (kg/acer)	Dynamic model output	Chill hour model output
Volk oil treatment	Mehrabad	47 a	40.7 a	7.4 c	2.43 c	1.5 c	33.7 a	2294.6 a	915.9 a	35 CP	540 h
	Estabragh	46 a	40.5 a	7.83 bc	2.5 bc	1.5 c	33.8 a	2364.8 a	891.3 a	31 CP	465 h
	Robat (W)	41 b	33.8 b	8.51 bc	2.76 ab	2 b	33.7 a	1944.8 b	732.9 b	30 CP	571 h
	Robat (E)	41.1 b	33.4 b	9 ab	2.75 ab	1.8 b	34 a	1910.9 b	692 b	27 CP	445 h
	Khabr	39.2 b	31.2 b	9.9 a	2.8 a	2.1 a	34.12 a	1886.7 b	685.7 b	25 CP	457 h
Pearson correlation coefficients with *dynamic model*		0.97	0.88	–0.96	–0.93	–0.73	–0.98	0.90	0.89	–	–
Significant		**	*	**	*	*n.s*	**	*	*	–	–
Pearson correlation coefficients with *chill hour model*		0.88	0.22	–0.48	–0.29	–0.06	–0.70	0.12	0.28	–	–
Significant		*	*n.s*	*n.s*	*n.s*	*n.s*	*n.s*	*n.s*	*n.s*	–	–

Means followed by the same letters are not significantly different ($P \geq 0.01, 0.05$)
Prob > |r| under H0: $\rho = 0$
Volk oil in concentration of 50 liter/1000 l H_2O, applied on February 14, 2017, in all regions

Table 6 Pearson correlation coefficients of some reproductive growth parameters of pistach'o 'Akb'ri' variety with dynamic and chill hour model outputs, calculated in Shahrebabak different pistachio production regions includes Mehrabad, Estabragh, Robat (W), Robat (E) and Dasht-E-Khabr based hourly temperatures recorded by Data logger per each site, trough 2017–2018

Rest-breaking agent	Regions	Initial fruit set (%)	Final fruit set (%)	Blanking (%)	Half seed (%)	Malformed fruit (%)	Ounces	Fruit fresh (kg/acer)	Fruit dry (kg/acer)	Dynamic model output	Chill hour model output
Volk oil treatment	Mehrabad	40 a	33.05 a	8.36 c	2.16 a	0.63 b	23.35 a	1111.4 a	461.1 a	35 CP	540 h
	Estabragh	39.25 a	31.1 ab	8.81 bc	2.08 a	0.62 b	23.22 a	1059.8 ab	446.3 ab	31 CP	465 h
	Robat (W)	38 a	29.5 ab	8.67 bc	2.17 a	0.63 b	23.35 a	1065.1 ab	432.6 ab	30 CP	571 h
	Robat (E)	37.75 a	30.1 ab	9.26 b	2.23 a	0.67 ab	23.58 a	1028 ab	419.8 ab	27 CP	445 h
	Khabr	29.5 b	28.4 b	10.01 a	2.25 a	0.71 a	23.72 a	955.2 b	394.5 b	25 CP	457 h
Pearson correlation coefficients with *dynamic model*		0.80	0.91	–0.93	–0.68	–0.90	–0.80	0.94	0.97	–	–
Significant		*n.s*	*	*	*n.s*	*	*n.s*	*	**	–	–
Pearson correlation coefficients with *chill hour model*		0.41	0.29	–0.69	–0.25	–0.65	–0.48	0.64	0.51	–	–
Significant		*n.s*	*n.s*	*n.s*	*n.s*	*n.s*	*n.s*	*n.s*	*n.s*	–	–

Means followed by the same letters are not significantly different ($P \geq 0.01, 0.05$).
Prob > |r| under H0: $\rho = 0$
Volk oil in concentration of 50 liter/1000 l H_2O, applied on February 14, 2017, in all regions

correlation with the hill hour model (–0.70$^{n.s}$) (Table 5). The pistachio fresh (0.90*) and dry weights (–0.89*) were correlated with the dynamic model in a positive direction, but there was not a significant correlation with the chill hour model (0.12$^{n.s}$, 0.28$^{n.s}$). For 'Akbari' cultivar, a significant correlation of the chill hour model with the reproductive traits was not found (Table 6). The study of correlation coefficient of the initial fruit set indicated that this trait was not significantly correlated with the dynamic model (0.80$^{n.s}$). Significant positive associations were found between the final fruit set and the dynamic model (0.91*) for 'Akbari' cultivar. A negative association between blanking (–0.93*) and the dynamic model was found (Table 6). For this cultivar, there was not the significant relationship between the half kernel fruits and the dynamic model (–0.67*). A negative association was found between the malformed fruit and the dynamic model (–0.90*). The association trend for the number of pistachio nuts per ounce was similar in the half kernel fruit for 'Akbari' cultivar and had not a significant relationship with the dynamic model (–0.80*) (Table 6). The Pearson correlation, for the pistachio 'Akbari' fresh weight showed a positively and statistically significant correla-

tion with the dynamic model (0.94*). There was a highly positive significant correlation between the pistachio dry weight (kg) and the dynamic model outputs (0.97**).

Correlation between the Vegetative Growth Parameter and the Chilling Models

According to our results, there was not any significant correlation between the vegetative growth traits and the chill hour model for pistachio 'Owhadi' and 'Akbari' cultivars. Our findings revealed that the number of floral buds had a strong significant positive correlation with the dynamic model (0.97**), but there was no correlation between the number of leafy buds and the dynamic model (–0.70$^{n.s}$) (Table 7). The ratio of leafy to floral buds was significantly associated with the dynamic model in 'Owhadi' cultivar in a negative direction (–0.89*). There was no correlation between the length of shoots (cm) and the dynamic model (0.81$^{n.s}$), but the correlation was more than the chill hour model. The abscission of flower buds was highly correlated with the dynamic model in a negative direction, similarly to the number of floral buds (–0.97**) (Table 7). The vegetative growth traits of 'Akbari' cultivar showed a similar trend with 'Owhadi'. The number of floral buds was positively correlated (0.92*) with the dynamic model. A strong negative correlation was observed between the ratio of leafy to floral buds and the dynamic model (–0.89**) (Table 8). The length of shoots (Cm) was not correlated (0.81$^{n.s}$) with the dynamic model (Table 8). Similarly, to 'Owhadi' cultivar, there was a high negative significant correlation between

Table 7 Pearson correlation coefficients of some vegetative growth parameters of p'stachi' 'Owhadi' variety with dynamic and chill hour model outputs, calculated in Shahrebabak different pistachio production regions includes Mehrabad, Estabragh, Robat (W), Robat (E) and Dasht-E-Khabr based hourly temperatures recorded by Data logger per each site, trough 2017–2018

Rest-breaking agent	Regions	Leafy bud (No)	Floral bud (No)	Leafy to floral bud	Shoot length (cm)	Flower bud abscission	Dynamic model output	Chill hour model output
Volk oil treatment	Mehrabad	4.75 b	3.75 a	2.08 b	22.62 ab	0 a	35 CP	540 h
	Estabragh	4.37 b	3.75 a	2.03 b	22.87 a	2 a	31 CP	465h
	Robat (W)	5.12 ab	3.37 ab	2.22 b	22.62 ab	4 a	30 CP	571h
	Robat (E)	5 ab	3.12 ab	3.20 ab	22 ab	6.5 a	27 CP	445 h
	Khabr	5.62 a	2.62 b	3.56 a	21 b	6.5 a	25 CP	457 h
Pearson correlation coefficients with *dynamic model*		–0.70	0.97	–0.89	0.81	–0.97	–	–
Significant		*n*.s	**	*	*n*.s	**	–	–
Pearson correlation coefficients with *chill hour model*		–0.64	0.43	–0.63	0.50	–0.53	–	–
Significant		*n*.s	*n*.s	*n*.s	*n*.s	*n*.s	–	–

Means followed by the same letters are not significantly different ($P \geq 0.01, 0.05$)
Prob > |r| under H0: $\rho = 0$
Volk oil in concentration of 50 liter/1000 l H_2O, applied on February 14, 2017, in all regions

Table 8 Pearson correlation coefficients of some vegetative growth parameters of p'stachi' 'Akbari' variety with dynamic and chill hour model outputs, calculated in Shahrebabak different pistachio production regions includes Mehrabad, Estabragh, Robat (W), Robat (E) and Dasht-E-Khabr based hourly temperatures recorded by Data logger per each site, trough 2017–2018

Rest-breaking agent	Regions	Leafy bud (No)	Floral bud (No)	Leafy to floral bud	Shoot length (cm)	Flower bud abscission	Dynamic model output	Chill hour model output
Volk oil treatment	Mehrabad	4.62 a	5.87 a	0.80 b	26.50 a	10.5 b	35 CP	540 h
	Estabragh	4.62 a	5.87 a	0.82 b	26.62 a	12.75 c	31 CP	465h
	Robat (W)	4.5 a	5.5 ab	0.83 b	26 a	17 ab	30 CP	571h
	Robat (E)	4.62 a	5 bc	0.98 ab	26 a	13.25 b	27 CP	445 h
	Khabr	4.75 a	4.5 c	1.08 a	25.5 a	23.37 a	25 CP	457 h
Pearson correlation coefficients with *dynamic model*		–0.47	0.92	–0.90	0.84	–0.90	–	–
Significant		*n*.s	*	*	*n*.s	*	–	–
Pearson correlation coefficients with *chill hour model*		–0.70	0.51	–0.66	0.22	–0.18	–	–
Significant		*n*.s	*n*.s	*n*.s	*n*.s	*n*.s	–	–

Means followed by the same letters are not significantly different ($P \geq 0.01, 0.05$)
Prob > |r| under H0: $\rho = 0$
Volk oil in concentration of 50 liter/1000 l H_2O, applied on February 14, 2017, in all regions

the abscission percentage of floral buds and the outputs of dynamic model (–0.97**) (Table 8).

Discussion

The CH model is routinely used in Iran and many pistachio producing countries for reporting chilling accumulation for pistachios. Recently, we are facing to daily high temperature or temperature fluctuation in dormant season, especially in pistachio production regions. The chilling hour model doesn't address chill cancelation due to high temperatures during the dormant season (Dennis 2003; Perez et al. 2008). Furthermore, our experiments on two pistachio 'Owhadi' and 'Akbari' cultivars in mentioned condition, closed the distance of experimental sites with major difference in chilling accumulation. Two model for chill accumulation was used: dynamic and chill hour models, but there was not any significant correlation between the outputs of two mentioned model in different regions in this experiment ($0.61^{n.s}$). According to our results, the dynamic model of CP showed a greater accumulation of chill portion in Mehr Abad (35 CP), the steeper slope of curve for accumulated chill in the Estabragh region as well as the minimum slope of the curve of accumulated chill and the minimum accumulation of chill portions (CP) were observed in Dasht-e Khabr. According to the results, by applying the dynamic model, different experimental regions were completely differentiated, and there was a significant correlation between most of vegetative and reproductive traits with dynamic model. Consequently, the results provided by the dynamic model would contribute better to the differences of pistachio vegetative and reproductive traits between five regions. We proved that the dynamic models (DM) presented a better description of the actual condition in different regions. We can state that the results obtained by applying the dynamic model could be determining for the precision amount of the winter chill accumulation for pistachio trees in the central part of Iran as a sub-tropical condition. With reference to these findings, we can say that the dynamic model is an efficient one with high precision, especially for geographic zones with micro-climates, those are completely different from each other. The previous documents reported the optimal results of the dynamic model in location with high winter temperatures. The results of studies by Fishman et al. (1987) and Dennis (2003) are completely similar to our findings. Similar results reported by Perez et al. (2008) for *Vitis vinifera*, showed that the dynamic model was better than others, especially for warm Mediterranean climate. In regions with lack of winter chill, some growth abnormalities have been reported. Our results showed that the control treatment in Dasht-e Khabr had the maximum value of the abscission percentage of floral buds that could be related to lack of chilling. Lack of winter chilling in mild winter regions results in the uneven and abnormal patterns of budbreak and flower bud abscission, reported by Crossa-Raynaud (1955), Legave et al. (1982), Erez and Couvillon (1987), Erez (1999), Ben Mimoun (2008), Viti et al. (2010) and Campoy et al. (2012). A summer discussion in case of Volk oil was demonstrated the greatest advancement in some reproductive and vegetative growth, and the rate of kernel filling in the study done by Beede and Ferguson (2002) was similar to our findings which showed that Volk oil can completely alter the reproductive and vegetative traits. Based on our results, Volk oil treatment, by enhancing the vegetative growth of trees decreased high temperature effects on pollination and fertilization and also induced more homogamy with pistachio male trees, thereby decreasing blank nuts. Rahemi and Asghari (2004) showed that Volk oil could be effective in pistachio trees to increase blooming and improve kernel weight, lateral budbreak and percentage of flower buds as well as to improve synchronization of male and female flowers, which was completely parallel with our findings. Interesting point for the Volk oil treatment in Dasht-e Khabr was which it had a significant difference with other treated regions for 'Akbari' cultivar. The Volk oil treatment in Dasht-e Khabr could not increase initial fruit set, fruit size and number of floral buds for 'Akbari' cultivar like other regions and it was observed significant difference between them while treated by Volk. This can refer to climatic conditions, and the amount of chill accumulated before breaking agent treatment. The previous reports well descripted the effectiveness of winter breaking agent and their relationship with climatic conditions and the amount of chill accumulated before breaking agent treatment (Fuchigami and Nee 1987; Nee and Fuchigami 1992; Lloyd and Firth 1993; Zhang and Taylor 2011).

Conclusion

Currently, the chilling hours (CH) model is widely used in Iran and is annually reported by different centers without considering the impact of high winter temperatures and daily temperature fluctuation on accumulated winter-chill. The chilling hours (CH) model cannot differentiate between various regions in such conditions. Therefore, the replacement of the CH model by the DM model can be beneficial to calculate accumulated winter-chill in pistachio production regions.

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Declarations

Conflict of interest M. J. Mahmoudi Meimand, H. Alipour, M. H. Shamshiri and M. Esmaeili Zadeh declare that they have no competing interests.

Ethical standards For this article no studies with human participants or animals were performed by any of the authors. All studies performed were in accordance with the ethical standards indicated in each case.

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