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气候变化背景下陇东塬区‘红富士’苹果始花期研究

张艳艳[1],赵 玮[1],高庆先[2],张谋草[3]

([1]河北省廊坊市气象局,河北廊坊 065000;[2]中国环境科学研究院·环境基准与风险评估重点实验室,北京 100012;[3]甘肃省庆阳市气象局,甘肃庆阳 745000)

摘 要:【**目的**】分析苹果始花期对气候变化的响应,提取主要影响气象因子,并提出优势苹果花期预报方法;为苹果开花期气象灾害防御和管理措施的调整提供科学依据。【**方法**】采用偏最小二乘回归法对西峰农业气象试验站多年观测的苹果始花期与光、热、水气象因子进行分析,并开展了苹果始花期预测。【**结果**】苹果始花期的早晚与2月下旬至4月上旬的旬平均气温及3月平均气温呈显著负相关;苹果开花日期与积温呈现显著的相关性,≥0 ℃、≥5 ℃积温越大或<0 ℃积温越小,花期出现越早,反之则迟;说明气温升高,开花日期出现早,反之则迟。苹果始花期与稳定通过10 ℃初日接近,较稳定通过5 ℃初日晚超过20 d。利用偏最小二乘回归模型预报苹果始花期,预测日期与实际日期相符率为97%。【**结论**】影响陇东苹果开花早晚的主要影响因素是热量因子,日照次之,降水影响最小,气候变暖和高光照使苹果始花期提前。偏最小二乘回归模型预测苹果始花期较传统回归模型和线性分析法预报苹果始花期更为科学。

关键词:苹果始花期;气候变化;陇东塬区

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The effect of climate change on the apple's initial flowering date in the eastern Gansu province

ZHANG Yanyan[1], ZHAO Wei[1], GAO Qingxian[2], ZHANG Moucao[3]

([1]*Langfang Meteorological Bureau, Langfang 065000, Hebei, China;* [2]*Chinese Research Academy of Environmental Sciences · State Key Laboratory of Environmental Criteria and Risk Assesment, Beijing 100012, China;* [3]*Qingyang Meteorological Bureau, Qingyang 745000, Gansu, China*)

Abstract:【Objective】This article primarily analyzes the effect of climate change on the apple's initial flowering date. The most important meteorological factors will be identified. Two methods will be used to forecast the apple's initial flowering date in this article. Some scientific results will be provided to better allow for identifying meteorological disasters before they occur.【Methods】Used partial least square regression method to analyze the correlations between the apple's initial flowering date and meteorological factors. Use the improved accumulated temperature method, linear correlation method and partial least square regression model to forecast the apple's initial flowering date. Meteorological factors about light, heat, water were obtained from the Xifeng Agricultural Meteorological Station's observations. Data about apple florescence were obtained from the Xifeng Agricultural Meteorological Station which is located at Dongzhi Loess Plateau, Qingyang city, Gansu province. The observed variety of apples for testing was the 'Red Fuji' apple. Meteorological data was obtained from the Xifeng National Based Station in Gansu province. The years used for testing were all 22 years from 1994 to 2015.【Results】(1) There was a significant negative correlation between the date of apple florescence and the averange temperature from February to early April. There was a low correlation between the date of apple florescence and the average temperature from November last year to January this year. When the average temperature was higher, the apple blossomed earlier. (2) There was a significant correlation between the accumulated temperature (accu-

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作者简介:张艳艳,工程师,在读硕士研究生,主要从事农业气象科研和服务工作。E-mail:yanyanzhang0322@126.com

mulated temperature≥0 ℃ and ≥5 ℃) and the apple's initial flowering date during November 1st last year to April 10th this year. The larger the accumulated temperature, the earlier the apple's initial flowering date. It indicated, with the heat condition increasing year by year, that the apple's initial flowering date also showed an advancing trend. The warmer winter temperatures make apple trees safer to go through the winter. (3) When the average temperature from March to early April was higher than the minimum temperature for the growth of apple trees, the apple's initial flowering date was more than 20 days behind the first date of 5 ℃, and was closer to the first date of 10 ℃. (4) The relationship between ten days or more of monthly precipitation and the apple's initial flowering date had very little correlation. Therefore, precipitation was not the factor that restricted the blossoming date of the apples. (5) There was a strong negative correlation between the apple's initial flowering date and the sunshine duration in early January and March. Especially in March, the sunshine duration had passed the $\alpha_{0.05}$ significance test, which means in March, when the sunshine duration has increased, the apple's initial flowering date will also advance. (6) In using the improved accumulated temperature model to forecast the apple's initial flowering date from 1994 to 2015, there was a 81.8% year forecast date which was closer to the actual date. The maximum time difference was 16 days. The years with errors of more than 7 days reached 5 years. Then forecasted date of the apple's initial flowering date in 2013 was April 23th, while the actual date was April 7th. When the forecasted apple's initial flowering date was determined by using the linear correlation method, the difference between the forecast of the remaining 21 years and the actual date was smaller, there was a 95.5% year forecast date which was closer to the actual date. When the forecasted apple's initial flowering date was determined by using the partial least square regression model, the difference between the forecast of the remaining 21 years and the actual date was similar, there was a 97% year forecast date which was closer to the actual date. (7) The partial least square regression model for forecasting the apple's initial flowering date in the east of Gansu province provided much better results. By accurately predicting the apple's initial flowering date, fruit farmers can adjust the apple flowers density and can also determine frost damage defense in the early spring.【Conclusion】(1)The apple's initial flowering date was primarily effected by light, heat, water and other meteorological elements. If the meteorological elements are sequenced, the major factor is heat, followed by sunshine, with precipitation being the minimal effect factor. Global warming and high illumination help to make the apple's initial flowering date advance. (2) The research results about the apple's flowering response to climate change was the same as other experts and scholars, but there are some differences with Lee Mi-Ying's study results, such as, the average temperature during early February to early April was more important for the apple's initial flowering date and the average temperature in March was the most important factor. Also it was concluded that precipitation was not the key factor effecting the condition of the apple's initial flowering date, but Lee Mi-Young's study results show that the apple's initial flowering date will be inhibited by excessive rainfall. (3) The linear correlation method is a more reliable forecast for the apple's initial flowering date than the improved accumulated method. This article primarily discussed the effect of meteorological factors on the apple's initial flowering date, however, the apple's initial flowering date also was affected by apple tree management (such as fertilization, pruning, watering, covering with grass or black plastic film or straw, etc.) and tree-age, the effect of these factors needs to be further explored.

Key words: Apple initial flowering date; Climate change; Eastern Gansu province

植物物候期对气候变化的响应越来越受到专家学者的重视，在全球气候变化研究中，物候常被认为是反应气候与环境变化的重要指标[1-3]。欧洲的许多研究报道[4-5]表明，自20世纪80年代以后，由于气

候变暖,欧洲许多物候现象发生了明显变化,春季物候期提前,秋季物候期推迟。我国学者研究表明,随着平均温度上升,我国各种木本植物物候期出现相应的变化,春季提前,秋季推迟,绿叶期延长[6];春季物候对气候变化的响应程度显著大于秋季物候,大多数植物生殖生长期的物候变化幅度大于营养生长期[7]。较温暖的冬季也有利于虫卵安全越冬,虫害威胁加大[8]。苹果开花期的气象条件对当年苹果产量、品质具有决定性的作用,开展相关研究具有十分重要的经济价值和社会效益。

陇东黄土高原位于甘肃黄土高原腹地,这里黄土层深厚,水热同季,光照充足,昼夜温差大,是甘肃省优质苹果产地之一。苹果生长适宜气候条件分析、气候区划、生长发育、物候期以及冻害等一直是专家学者们的关注重点。朱琳等[9]、魏钦平等[10]开展了陕西苹果优质生产气候条件分析;前人[11-13]分析了苹果等作物对气候变化的响应以及气候变化对苹果生长的影响;蒲金涌等[14]、殷淑燕等[15]研究了气候变化对苹果物候期的影响。前人[16-18]开展了苹果花期冻害气象条件分析。毛明策等[19]等利用苹果物候观测和气象资料分析了温度对苹果初花期的影响;李美荣等[20-21]对陕西苹果始花期预测模型进行了研究。

近几年,陇东地区苹果花期出现不同程度的提前,导致管理措施出现了不适宜性,花期气象灾害防御也面临了更多的考验。笔者在前人研究成果的基础上,针对苹果花期对气候变化响应、花期预测等做了补充研究。利用西峰农业气象试验站22 a来(1994—2015年)苹果花期物候观测资料和西峰基本气象观测站气象数据,从气象因子(温度、降水、日照)变化对苹果始花日期(以下简称始花期)的影响入手,引用偏最小二乘回归(以下简称PLSR)方法,分析苹果始花期对气候变化的响应,提取主要影响气象因子,有效解决了降水、气温、积温等气象要素多重相关问题,比传统预测方法更加精确,为苹果开花期气象灾害防御和管理措施的调整提供科学依据。

1 资料来源和计算方法

1.1 资料来源

苹果始花期资料取自位于甘肃省庆阳市董志塬的西峰农业气象试验站,观测品种为'红富士'。气象数据取自西峰基本气象观测站。年限均为22 a(即1994—2015年)。

1.2 果园基本情况

对苹果始花期观测的果园土壤为壤土,无灌溉,果树树龄为22 a,种植密度为每666.7 m^2 40~55株。

1.3 计算方法

日平均气温达到5、7、10 ℃起始日期的确定采用5日滑动平均法。≥0 ℃、≥5 ℃及＜0 ℃积温是统计了前一年11月1日至当年4月10日之间每天≥0 ℃、≥5 ℃及＜0 ℃日平均气温之和。日平均气温达到5、7、10 ℃的起始日期及苹果始花期以3月1日为1,转化成相对应的天数,得到逐年日平均气温达到5、7、10 ℃日期及苹果始花期的天数序列,用此天数序列与气象因子进行相关分析。数据分析和图形制作由SPSS和SIMCA-P软件完成。

2 结果与分析

2.1 热量变化对苹果始花期的影响

2.1.1 平均气温变化对苹果始花期的影响 利用前一年11月至当年4月上旬的旬平均气温、月平均气温等不同时间段平均气温与当年出现的始花期进行相关分析,结果表明,花期出现与当年2月以后不同时段平均气温显著相关,与前一年11月至当年1月气温变化相关性较低。因此表1只列出了2月至4

表1 2月上旬至4月上旬不同时段平均气温与始花期的相关系数

Table 1 The correlation coefficient between average temperature and the apple's initial flowering date during early February to early April

2月上旬 Early Feb.	2月中旬 Mid-Feb.	2月下旬 Late Feb.	3月上旬 Early Mar.	3月中旬 Mid-Mar.	3月下旬 Late Mar.	4月上旬 Late Mar.	2月 Feb.	3月 Mar.	2月下旬至3月中旬 Late Feb.to early Mar.	3月中旬至4月上旬 Mid-Feb. to early Apr.
-0.207 1	-0.341 9	-0.361 8*	-0.429 6**	-0.460 2**	-0.613 0***	-0.449 3**	-0.419 2*	-0.733 7***	-0.617 5***	-0.703 0***

注:*表示通过 $\alpha_{0.1}$ 的显著检验,**表示通过 $\alpha_{0.05}$ 的显著检验,***表示通过 $\alpha_{0.01}$ 的极显著检验(n=22)。下同。

Note: * is indicated by a significant test of $\alpha_{0.1}$, ** is indicated by a significant test of $\alpha_{0.05}$, *** is indicated by a significant test of $\alpha_{0.01}$ (n=22). The same below.

月上旬各时段平均气温和始花期相关系数。由表1可知,苹果始花期与3月下旬、3月、2月下旬至3月中旬、3月中旬至4月上旬的平均气温呈极显著负相关,其相关性通过$\alpha_{0.01}$显著检验,说明平均气温越高,苹果花期越早。

2.1.2 积温变化对苹果始花期的影响 果树完成某一发育期需要一定的温度积累,通过对前一年11月1日至当年4月10日≥0 ℃、≥5 ℃及<0 ℃的活动积温与当年始花期相关性分析(表2)得知,其相关性达显著水平,≥0 ℃、≥5 ℃积温值越大,或<0 ℃积温值越小,苹果花期越早,反之苹果花期迟。可根据≥0 ℃、≥5 ℃、<0 ℃积温统计值的大小,预计苹果开花的迟早,并根据天气气候预测,针对春季低温或晚霜冻提供相应的预防措施,为预防苹果开花期受灾提供科学保障。

表2 前一年11月1日至当年4月10日不同活动积温与始花期的相关系数

Table 2 The correlation coefficient between accumulated temperature and the apple's initial flowering date during November 1st last year to April 10th this year

≥0 ℃积温 ≥0 ℃ accumulated temperature	≥5 ℃积温 ≥5 ℃ accumulated temperature	<0 ℃积温 <0 ℃ accumulated temperature
−0.711 5***	−0.707 8***	0.516 8**

2.1.3 温度年际变化对苹果始花期的影响 采用线性(*K*值)的估计方法[20],计算了对苹果始花期影响较大时段的热量因子变化趋势(表3),可知影响始花期的热量因子随年代增加而呈现增加趋势,只有3月上旬及<0 ℃积温随年代变化呈现出较弱的减少趋势,且<0 ℃积温减少,说明冬季气温变暖,对果树安全越冬有利,越冬受害减少;始花期随年代增加呈现出提前趋势。

表3 不同界限间积温、旬、月平均气温及始花期随年代变化趋势

Table 3 Accumulated temperture, ten-day and monthly average temperature and the apple's initial flowering date trends along with the year changed

因子 Factors	≥0 ℃积温 ≥0 ℃ accumulated temperature	≥5 ℃积温 ≥5 ℃ accumulated temperature	<0 ℃积温 <0 ℃ accumulated temperature	3月上旬平均气温 Average temperature of early Mar.	3月中旬平均气温 Average temperature of mid-Mar.	3月下旬平均气温 Average temperature of late Mar.	4月上旬平均气温 Average temperature of early Apr.	3月平均气温 Average temperature of Mar.	始花期 Apple initial flowering date
*K*值 *K* value	7.98	7.30	−2.85	−0.03	0.27	0.19	0.08	0.14	−0.50
*R*值 *R* value	0.59	0.54	0.22	0.06	0.59	0.46	0.25	0.49	0.46
通过α检验 α test	r_α=0.01	r_α=0.01			r_α=0.01	r_α=0.05		r_α=0.05	r_α=0.05

2.1.4 日平均气温达到5、7、10 ℃起始日期对始花期的影响 以3月1日为1,将日平均气温达到5、7、10 ℃起始日期及始花期转化为天数时间序列,分析了始花期与各界限温度初日间关系,发现始花期落后日平均气温达到5 ℃起始日期20 d以上(除2001、2006、2010年外),而与日平均气温达到10 ℃起始日期接近。但在1996和2015年,始花期与日平均气温达到10 ℃起始日期相比,分别推后20和18 d,主要是1996年3月1日至4月10日持续低温,其间平均气温仅为2.0 ℃,达不到果树生长最低温度(5.0 ℃)的要求,在4月中旬后气温迅速回升,果树开始生长;2015年是由3月至4月上旬阴天较多、日照时数偏少所致,2015年3月日照时数及4月上旬日照时数仅为167.8和46.7 h,分别是观测的22 a中第4和第2个日照时数少的年份。而2001、2002、2004和2013年始花期与日平均气温达到10 ℃起始日期相比,分别提前19、17、20和16 d,主要是由于这些年份开春后(3月)气温异常偏高,但日平均气温变幅大,因此使日平均气温达到10 ℃起始日期推迟。

2.2 降水量对苹果始花期的影响

分析了前一年11月至当年4月各旬及月降水量与始花期的相关性(表4),发现旬、月降水量的变化与始花期相关性较低。说明在该区降水量不是制约苹果树开花迟早的关键因子。

2.3 日照时数对苹果始花期的影响

分析前一年11月至当年4月各旬及月日照时数与始花期的相关性(表4),发现前一年11月至12月旬、月日照时数的变化对始花期的影响较小;只与当年1月上旬、3月中旬及3月日照时数呈现较强的负相关,特别是3月日照时数通过$\alpha_{0.05}$的显著检验。说明此阶段日照时数增加,苹果的始花期可提早。而2015年3月中旬至4月上旬的平均气温为8.0 ℃,与

表4　11月至4月各旬、月降水量、日照时数与始花期的相关系数

Table 4 The correlation coefficient between ten-days of precipitation, monthly precipitation, sunshine and the apple's initial flowering date during November 1st last year to April 10th this year

	11月上旬 Early Nov.	11月中旬 Mid- Nov.	11月下旬 Late Nov.	12月上旬 Early Dec.	12月中旬 Mid-Dec.	12月下旬 Late Dec.	1月上旬 Early Jan.	1月中旬 Mid-jan.	1月下旬 Late Jan.	2月上旬 Early Feb.	2月中旬 Mid-Feb.
降水量 Precipitation	0.01	0.31	−0.11	−0.026	0.36*	0.19	−0.28	−0.03	0.03	−0.02	−0.20
日照时数 Sunshine time	0.12	−0.14	0.09	−0.024	0.16	0.12	0.39*	−0.07	−0.09	0.13	0.16

表4（续）　Table 4 （continued）

	2月下旬 Late Feb.	3月上旬 Early Mar.	3月中旬 Mid-Mar.	3月下旬 Late Mar.	4月上旬 Early Apr.	11月 Nov.	12月 Dec.	1月 Jan.	2月 Feb.	3月 Mar.	11月1日至4月10日 Nov. to Apr. 10th
降水量 Precipitation	−0.01	−0.02	0.26	0.12	−0.05	0.07	0.21	−0.09	−0.15	0.19	0.06
日照时数 Sunshine time	−0.08	−0.12	−0.42*	−0.27	−0.31	0.05	0.14	0.09	0.10	−0.46**	−0.13

常年的6.2 ℃相比偏高1.8 ℃,降水量为61.2 mm,与常年相比多1倍,日照时数为214.5 h,比常年的260.9 h少46.4 h;因而2015年开花日期与10 ℃初日日期相比推后18 d,主要是由光照不足引起的。

2.4　苹果始花期预报

数理统计法、多元回归法、积温法和相关分析法均能够预测作物物候期[20,22-24],但普遍认为积温法和相关分析法是花期预报较好的方法。笔者利用积温法和相关分析法对陇东苹果始花期进行预报,并引入了偏最小二乘回归模型进行苹果花期的预测,对比了3种预测方法的准确性。

2.4.1　*积温法预报苹果始花期*　利用改进后的积温模式[24]预报苹果始花期。

$$d=\frac{T-T'}{\bar{t}-K} \qquad (1)$$

(1)式中:d为苹果芽膨大后某一天至预测的始花期的时间(d),T为芽膨大至始花期的有效积温(℃),T'为芽膨大至某一天已有的有效积温(℃),$\bar{t}$为进行预报期内的预报平均温度(℃),K为苹果果树的生物学零度(℃)。其中T和K利用下列(2)和(3)式计算。

$$T=\frac{\sum Y}{n}-K\cdot\frac{\sum X}{n} \qquad (2)$$

$$K=\frac{n\sum XY-\sum X\cdot\sum Y}{n\sum X^2-(\sum X)^2} \qquad (3)$$

(2)、(3)式中:X为芽膨大至初花的持续时间(d),Y为芽膨大至初花的活动积温(℃),n为资料年代(22 a)。

由此(1)式变换为:$d=\frac{94.1-T'}{\bar{t}-6.1}$　(4)

利用(4)式对1994—2015年的苹果始花期进行了预测(表5),发现1997、2001、2010和2013年这4 a预测日期和实际始花期相差较大,其余18 a预测日期与实际日期基本接近,并对2016年进行预测,T'为芽膨大(3月25日)至某一天(3月31日)已有的有效积温,为26.1 ℃,$\bar{t}$为2016年预报的平均温度,为10.0 ℃,计算得2016年开花初日是4月17日,实际出现日期是4月18日。

2.4.2　*相关分析法预报苹果始花期*　由前面的分析可知,陇东地区苹果花期主要是由当年开春后气温的变化决定的,而降水量和日照时数的多少对其开花迟早的影响较小。同时发现开花时间与3月平均气温相关性较高,因此笔者以3月平均气温为预报因子自变量,以始花期转换为相应天数为预报因子因变量,得出线性回归预报方程是:

$$D=64.2-2.7\times T_{3月平均气温}$$

$$(R=0.717\,8, F=21.262\,7>F_{0.000\,2}) \qquad (5)$$

(5)式中:D是以3月1日为1,至开花初日时对应的天数,$T_{3月平均气温}$为3月平均气温。对1994—2015年的苹果始花期进行了预测(表5)。只有1997年误差较大,相差10 d,其余21 a的预报值和实测值相差较小。并利用(5)式对2016年苹果始花期进行预测,3月平均气温为6.5 ℃,计算得出D=47,预测得2016年苹果始花期为4月16日,实际出现日期是4月18日。

由表5中计算得积温法和线性相关预测值与实

表 5 实际始花期与预测始花期

Table 5 Actual and forecast for the apple's initial flowering date

年份 Year	实际始花期 Actual apple initial flowering date	积温法预测始花期 Forecast the apple initial flowering date by improved accumulated temperature method	实际始花期与积温法预测误差 The error between actual apple initial flowering date and forecast date by improved accumulated temperature method	相关法预测始花期 Forecast the apple initial flowering date by linear correlation method	实际始花期与相关法预测误差 The error between actual apple initial flowering date and forecast date by linear correlation method	偏最小二乘回归法预测始花期 Forecast the apple initial flowering date by PLSR	实际始花期与相关法预测误差 The error between actual apple initial flowering date and forecast date by PLSR
1994	1994-04-30	1994-04-25	5	1994-04-26	4	1994-04-27	3
1995	1995-04-27	1995-05-03	-6	1995-04-23	4	1995-04-23	4
1996	1996-05-05	1996-05-01	4	1996-04-29	6	1996-05-05	0
1997	1997-04-29	1997-04-19	10	1997-04-19	10	1997-05-01	-2
1998	1998-04-20	1998-04-17	3	1998-04-27	-7	1998-04-21	-1
1999	1999-04-21	1999-04-18	3	1999-04-20	1	1999-04-20	1
2000	2000-04-16	2000-04-19	-3	2000-04-16	0	2000-04-19	-3
2001	2001-04-12	2001-04-27	-15	2001-04-18	-6	2001-04-16	-4
2002	2002-04-12	2002-04-16	-4	2002-04-16	-4	2002-04-14	-2
2003	2003-04-26	2003-04-18	8	2003-04-23	3	2003-04-25	1
2004	2004-04-14	2004-04-15	-1	2004-04-19	-5	2004-04-13	1
2005	2005-04-15	2005-04-14	1	2005-04-21	-6	2005-04-18	-3
2006	2006-04-14	2006-04-13	1	2006-04-16	-2	2006-04-14	0
2007	2007-04-14	2007-04-10	4	2007-04-21	-7	2007-04-13	1
2008	2008-04-21	2008-04-20	1	2008-04-13	8	2008-04-18	3
2009	2009-04-15	2009-04-13	2	2009-04-16	-1	2009-04-14	1
2010	2010-04-27	2010-05-10	-13	2010-04-21	6	2010-04-27	0
2011	2011-04-25	2011-04-21	4	2011-04-26	-1	2011-04-24	1
2012	2012-04-20	2012-04-23	-3	2012-04-22	-2	2012-04-20	0
2013	2013-04-07	2013-04-23	-16	2013-04-07	0	2013-04-06	1
2014	2014-04-16	2014-04-17	-1	2014-04-14	2	2014-04-04	2
2015	2015-04-19	2015-04-22	-3	2015-04-18	1	2015-04-16	4
2016	2016-04-18	2016-04-17	1	2016-04-16	2	2016-04-18	0
误差绝对值和 Sum of absolute error			111		86		38

际值误差的绝对值的和可知，线性回归法预测始花期与实际开花期接近，但出现了5次6~7 d的误差，因此用线性回归模式进行开花期预测存在不合理之处。

2.4.3 PLSR方法[25-26]预报苹果始花期 PLSR（偏最小二乘回归）方法在变量系统中提取若干对系统具有最佳解释能力的新综合变量，然后利用这些变量进行回归建模，建模算法如下：

预测因子和预测量矩阵分别记为E_0和F_0：

$$E_0=\begin{bmatrix} x_{11}^{*} \cdots x_{1m}^{*} \\ \vdots \ \ddots \ \vdots \\ x_{n1}^{*} \cdots x_{nm}^{*} \end{bmatrix} = \quad F_0=\begin{bmatrix} y_1^{*} \\ \vdots \\ y_n^{*} \end{bmatrix} \quad (1)$$

式（1）中$x_{ij}^{*}=\dfrac{x_{ij}-\bar{x}_j}{S_j}$，i=1，2，⋯；j=1，2⋯，m，表示第j个气象预报因子第i次观测的标准化值；$y_j^{*}=\dfrac{y_i-\bar{y}}{S_y}$，i=1，2，⋯，n，表示第i次观测对应的预测量标准化值；$\bar{x}_j$，$\bar{y}$分别为第j个预测因子和预测量的平均值，S_j，S_y分别表示第j个预测因子和预测量的标准差。

从E_0中个提取第一主成分t_1，$t_1=E_0w_1$，$w_1=\dfrac{E_0^TF_0}{\|E_0^TF_0\|}$，且$\|W_1\|=1$，实施$E_0$和$F_0$在$t_1$上的回归：

$$\begin{cases} E_0=t_1P_1^T+E_1 \\ F_0=t_1r_1^T+F_1 \end{cases} \quad (2)$$

式（2）中，E_1和F_1分别是E_0和F_0的残差矩阵，P_1^T

和 r_1^T 是回归系数,即 $p_1=\frac{E_0^T t_1}{\|t_1\|^2}$,$r_1=\frac{F_0^T t_1}{\|t_1\|^2}$。交叉检验 y 对 t_1 回归方程的收敛性,若精度达到要求,则继续进行,否则重复循环,直至精度达到要求。得到回归方程,即:

$F_0=r_1t_1+r_2t_2+\cdots+r_ht_h$(3)

式(3)$t_1,t_2,\cdots,t_h$ 是 E_0 的线性组合,可得 $F_0=r_1E_0w_1^*+r_2E_0w_2^*+\cdots+r_hE_0w_h^*$,其中 $w_h^*=\prod_{j=1}^{h-1}\left(I-w_jp^T\right)w_h$,$I$ 为单位矩阵。逆标准化得:

$y=a_0+a_1x_1+\cdots a_mx_m$(4)

式(4)中,$a_0,a_1,\cdots a_m$ 为方程系数。

3 讨 论

关于气候变化对苹果花期的影响,陕西、山东等地的果树研究者均做了大量工作,取得了较大成绩。但研究成果大多停留在生长适宜性、气候资源区划以及灾害风险等方面,花期预测方法也比较传统。笔者从气候变化的角度讨论了气象因子对苹果始花期的影响情况,查找了主要影响因子和主要影响时间段,结果表明降水不是制约苹果树开花迟早的关键因子,此结论与李美荣等[20,23]降水较大抑制开花的结论有异。

文中对比了PLSR方法与传统花期预测方法的准确性,目前花期预测的方法多采用相关分析法、回归法和积温法,花期预测结果表明,在部分年份出现较大误差,在实际应用中可信度不高;而PLSR方法要更加精确,具有实用价值。

本文在分析气象因子对始花期的影响时未考虑果园的管理(如施肥、生草覆盖、黑膜覆盖、秸秆覆盖等)、树龄及前一年挂果量等因素,这有待进一步探讨。

4 结 论

热量条件和光照条件是影响苹果开花的主要气象因素,降水是次要因素,气候变暖和高光照使苹果始花期提前。利用改进后的积温模式以及相关分析法预报22 a的苹果始花期,预测日期与实际日期分别相差111 d和86 d,最大误差年份预测日期与实际日期分别相差16 d和10 d,PLSR方法预测预报苹果始花期更为可靠,最大误差年份预测日期与实际日期相差4 d。把握苹果始花期对气候变化的响应规律,运用优势花期预测方法,科学预测苹果始花期,可为提前预防晚霜冻及强降温提供科学依据。

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