

Modeling Saffron Flowering Time Across a Temperature Gradient

Mamad A. Behdani¹, Mehdi Nassiri² and Alireza A. Koocheki²

¹Faculty of Agriculture, Birjand University

²Center of Excellence for Special Crops, Ferdowsi University of Mashhad
Iran

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Abstract

The objective of this study was to develop a thermal model that can be used for prediction of saffron flowering time. For this purpose, existing data on saffron flower emergence time were collected in a wide range of temperature regimes over the saffron production regions of Khorasan province (Iran). Linear second-order polynomial and 5-parameter beta models were used and statistically compared for their ability in predicting saffron flowering time as a function of temperature. The results showed a significant delay in flowering date across the temperature gradient. While beta model had a better statistical performance but the simple linear model also showed a good predicting ability and therefore, can be used as a reliable model.

INTRODUCTION

Khorasan province is known as the major saffron production areas of Iran. Although early autumn is the expected time for saffron flowering in the province, there is a considerable variation in flower emergence across the region. Matching this variation calls for quantitative understanding of flowering response of saffron to unexpected environmental variability.

Development is an irreversible process of change in the state of a plant, which generally progresses according to a more or less fixed and species-specific pattern (Atkinson and Porter, 1996). Many developmental stages are crop specific such as silking in maize, double ridge in wheat, or tuber formation in potatoes. While all these stages occur after a substantial vegetative growth, flowering in saffron is a unique process that starts before regular vegetative events such as leaf appearance and growth (Kafi et al., 2002). Therefore, known approaches for quantitative prediction of developmental stages in field crops e.g. growth degree days (GDD) or photothermal units (PTU) cannot easily be applied to saffron.

Flower emergence in saffron is influenced by factors such as radiation, nutrients and water availability. However, previous studies have shown that it is principally controlled by temperature (Kafi et al., 2002) and therefore, temperature would be the main criteria for estimating the time of flower emergence in this plant.

Robertson (1968) was one of the first to develop a model relating development rate to temperature and photoperiod. He used a quadratic function to explain nonlinear effects of these variables on development rate of wheat while taking into account response to day and night temperatures separately. Such a nonlinear models have been frequently used for predicting development in different crops (Gao et al., 1992; Grimm et al., 1993; among others). Summerfield et al. (1991) suggested a different approach based on the fact that despite any specific response to day or night temperatures in some plant species, over the wide range of conditions, mean daily temperature is the main driving force of a crop to flowering. Subsequently this method shown to be useful in predicting flowering times in various crops (Summerfield et al., 1993; Ellis et al., 1994) and could be reliable for saffron as well.

Flower initiation in saffron starts in the late spring, however, flowers will appear in the early autumn. Accurate estimation of this time should be helpful for planning harvest practices, which is highly dependent on local labours. While there are a large body of literatures on quantitative models for predicting flowering time in many plant species, to the best of our knowledge such a study is not yet reported for saffron.

Therefore, this paper aims to test different existing thermal models for estimating saffron flower emergence time over a wide range of temperature gradients.

MATERIALS AND METHODS

Existing data of saffron flowering time were collected in a wide range of temperature regimes over the saffron production regions of Khorasan province. Days to flowering (DTF) was defined as the number of days from the first of October to flower emergence and these data was collected from saffron fields with different ages in four main saffron production areas of the province including Torbat, Gonabad, Birjand and Ghaen. These areas were chosen across a temperature gradient and long term mean temperatures of September in studied areas were used as the predictor of DTF.

Linear (Eq. 1; Summerfield et al., 1991), second-order polynomial (Eq. 2) and 5-parameter Beta model (Eq. 3; Yin, 1996) were used and statistically compared for their ability in predicting saffron flowering time as a function of temperature.

$$\begin{aligned} DR &= B (T - T_b) && \text{if: } T < T_o \\ DR &= C (T_c - T) && \text{if: } T > T_o \end{aligned} \quad (1)$$

$$DR = A + BT - CT^2 \quad (2)$$

$$DR = \exp(\mu) (T - T_b)^\alpha (T_c - T)^\beta \quad (3)$$

Where DR = rate of development (day^{-1} , inverse of time from the first of October to flowering), T=mean temperature of October, T_b =base temperature ($^{\circ}\text{C}$), T_c =ceiling temperature ($^{\circ}\text{C}$), T_o = optimum temperature ($^{\circ}\text{C}$) and A, B, C, μ , α , β are model parameters. T_o is the zero of the first derivative of DR in Beat model so that:

$$T_o = \alpha T_c + \beta T_b / (\alpha + \beta) \quad (4)$$

Models were fitted using the nonlinear regression procedure of SigmaStat[®] for Windows Ver. 1.01, San Rafael, CA.

RESULTS

Development rate (DR) of saffron showed a unique response to mean September temperature, which was identical for three models. DR increased with temperature to a maximum at T_o and decreased to zero at T_c (Figure 1). In the Polynomial and to some extent in Linear model DR response to temperature was symmetric around T_o , but with Beta model in temperatures above T_o , DR was sharply dropped to zero, which shows more realistic performance of Beta compared to other models.

All of the three models studied were able to reliably predict the development rate of saffron with r^2 of 0.79, 0.87 and 0.99 for Linear, Polynomial and Beta models, respectively. However, the best and more realistic estimate of cardinal temperatures (T_b , T_o and T_c) was obtained by Beta model (Table 1). Estimated base temperature (T_b) was the same for Polynomial and Beta models, however, optimum and ceiling temperatures were different depending on the fitted model. Using these models days to flowering (DTF) at different temperatures could be predicted as the inverse of DR as shown in Table 1 for maximum DR. At optimum temperature, saffron flower emergence starts after 19 to 21 days from the beginning of October depending on the model used.

DISCUSSION AND CONCLUSION

Flowering time in saffron has a narrow range and is sensitive to unfavourable environmental conditions (Kafi et al., 2002). Therefore, precise prediction of this developmental event is crucial for obtaining a good yield (Atkinson and Porter, 1996). Since flowering in saffron, like many other plant species, significantly responds to temperature it would be possible to quantify this relation using regression models (Ellis et

al., 1990; Summerfield et al., 1993).

In this study three different models were used and statistically tested for their performance. While all of three models showed a good predicting ability, 5-parameter Beta model had a better estimate for cardinal temperatures and flower emergence time of saffron which were well corresponded to the existing data in the region (Kafi et al., 2002). This model was also used for prediction of flowering time in rice with reasonable results (Gao et al., 1992, Yin, 1996).

Saffron production areas of Khorasan province are extended over a wide range of climate with considerable differences in environmental conditions, mainly temperature, and flowering emergence of saffron varies over this temperature gradient. The results of this study showed that flowering time of saffron could be predicted from mean September temperature using simple linear model to more complicated Beta model with promising results

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Tables

Table 1. Estimated parameters of Linear, Polynomial and Beta models and the values of optimum temperature (T_o) and days to flowering from first of October (DTF) at T_o predicted using different models.

Model	Model Parameter										
	A	B	C	μ	α	β	T_b	T_c	T_o	DTF	r^2
Linear	-	0.76	0.812	-	-	-	8.92	33.4	22.1	19.7	0.79*
Polynomial	0.14	0.02	-0.004	-	-	-	10.2	31.2	21.8	20.5	0.87*
Beta	-	-	-	-	0.887	0.394	9.99	29.0	23.1	21.1	0.99*
				6.058							

* significant at $P < 0.05$

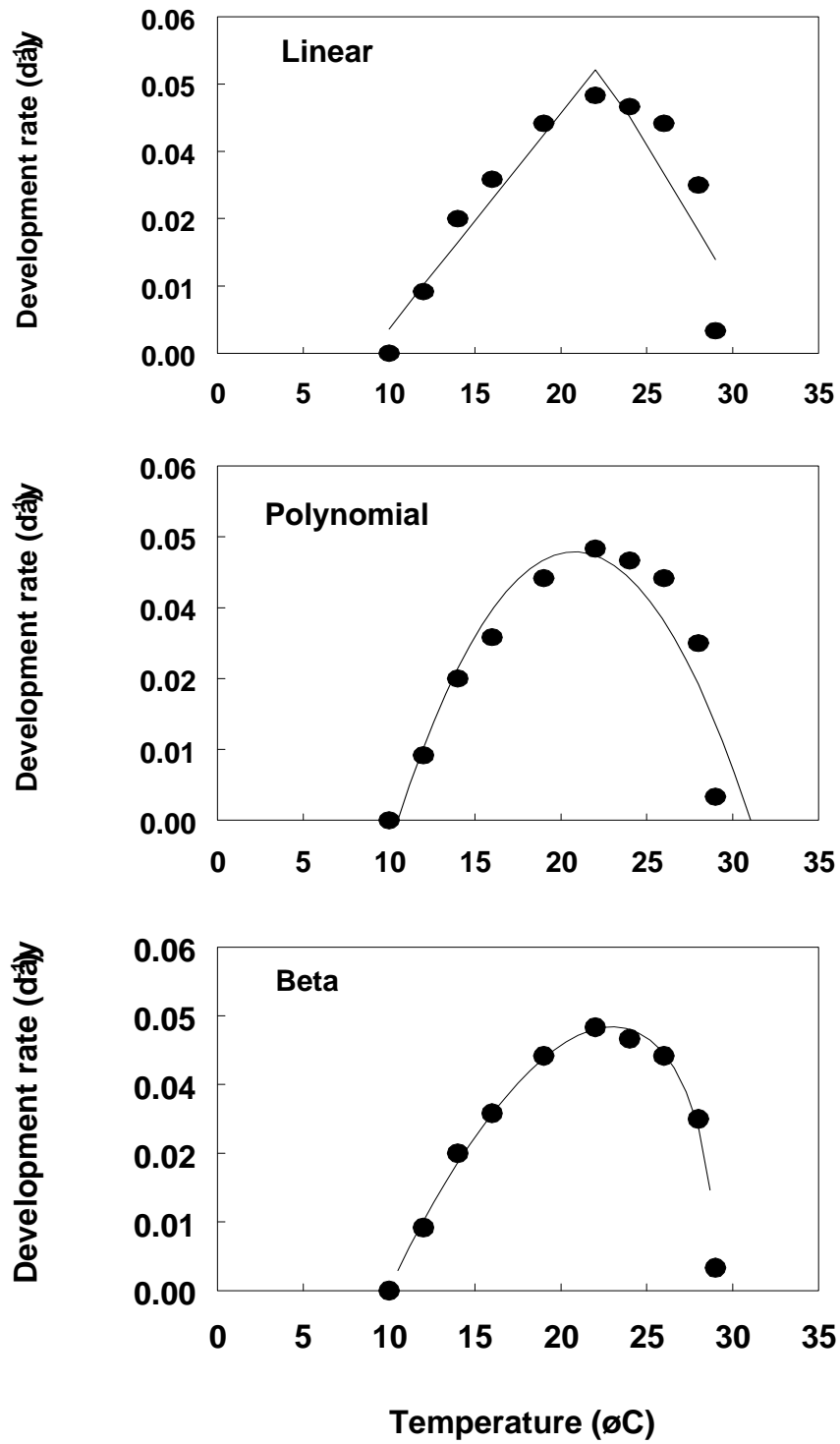


Fig. 1. Development rate of saffron as a function of mean September temperature. See text for description of models.