Industrial Crops & Products 122 (2018) 195–201

Contents lists available at ScienceDirect

Industrial Crops & Products

journal homepage: www.elsevier.com/locate/indcrop

Quantifying the germination response of spring canola (*Brassica napus* L.) to temperature

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ARTICLE INFO

Keywords:
Base temperature
Germination rate
Thermal time
Thermoinhibition
Normal distribution

ABSTRACT

The models based on thermal time concept have been widely applied to quantify the germination responses of seeds to temperature. The majority of these models assume a Normal distribution for both sub-optimal thermal time $\theta_{T(G)}$ and maximum temperature $T_{c(G)}$ to describe the variation in time to germination. In this study, the response of germination to temperature in six spring canola (*Brassica napus* L.) cultivars was described using the thermal time model.

Germination tests were carried out at constant temperatures of 8, 12, 16, 20, 24, 28, 32, 33, 34, 35 and 36 °C. The thermal time model accurately described germination patterns of different cultivars in response to temperature over sub- and supra-optimal. The thermal thresholds for seed germination, base temperature (T_b), sub-optimal thermal time needed to achieve 50% germination ($\theta_{T(50)}$), maximum germination temperature for induction of 50% thermoinhibition in seeds ($T_{c(50)}$) and supra-optimal thermal time to complete germination (θ_{Tc}) differed significantly among the canola cultivars studied. The values of T_b, $\theta_{T(50)}$, $T_{c(50)}$ and θ_{Tc} ranged from 4.86 to 7.10 °C, 358.89–407.19 °C h, 33.90–34.42 °C and 27.66–38.26 °C h, respectively. Within each cultivar optimum temperature ($T_{o(G)}$) showed little variation amongst different germination percentiles. The magnitude of $T_{o(50)}$ ranged from 31.86 to 32.25 °C depending on the cultivar. The thermal thresholds for seed germination identified here explained the differences in seed germination found among cultivars. All model parameters may be readily used in crop simulation models.

1. Introduction

In seed plants, seed germination is one of the important life history events, because it determines the time when a new life cycle is initiated (Weitbrecht et al., 2011). A wide range of external signals affects seed germination, including temperature (T), moisture, light, and nutrient availability (Gilbertson et al., 2014; Wang et al., 2016). Among these, T is one of the most important environmental determinants of capacity and rate of germination (Derakhshan et al., 2014; Kamkar et al., 2012). Base, optimum and maximum T (cardinal temperatures) characterize the limit of this environmental factor over which the germination of a particular species can occur. The base (T_b) and maximum (T_c) T are the temperatures below or above which seeds will not germinate, while the optimal T (T_o) is that at which germination is most rapid (Alvarado and Bradford, 2002; Mesgaran et al., 2017).

Mathematical models that describe the effects of T on progress toward germination have been constructed (e.g. Alvarado and Bradford, 2002; Covell et al., 1986). For the sub-optimal T range, seed germination time courses can be quantified on the basis of thermal time or heat units (Bradford, 2002). That is, the T in excess of T_b multiplied by the actual time to reach a specific germination fraction G (t_G), is a constant value for that fraction (the thermal time constant, $\theta_{T(G)}$):

$$\theta_{T(G)} = (T - T_b)t_G \text{ or}$$
$$GR_G = 1/t_G = (T - T_b)/\theta_{T(G)} \quad (1)$$

This equation predicts that the rate of germination for a specific seed fraction (GR_G) will increase linearly with T above T_b with a slope of $1/\theta_{T(G)}$ and an intercept on the T axis of T_b. The base T is often the same for all seed fractions in the population (Covell et al., 1986; Ellis et al., 1986; Kebreab and Murdoch, 1999). Similar models have been developed to characterize the time courses of germination at supra-optimal T range. Above T_o, GR_G decrease approximately linearly until T_c is reached and germination is prevented (Covell et al., 1986; Garcia-

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https://doi.org/10.1016/j.indcrop.2018.05.075
Received 14 September 2017; Received in revised form 16 April 2018; Accepted 29 May 2018
0926-6690/

Nomenclature

GR	Germination rate
T	Temperature
T_b	Base temperature
T_c	Maximum temperature
T_o	Optimum temperature
θ_T	Sub-optimal thermal time constant
θ_{Tc}	Supra-optimal thermal time constant

Huidobro et al., 1982). However, in contrast to a common T_b for all seeds in the population, it is often observed that different seed fractions have different T_c values. The following model accounts for this variation in T_c values (Bradford, 2002; Covell et al., 1986; Ellis et al., 1986):

$$\theta_{T_c} = (T_{c(G)} - T)t_G \text{ or}$$
$$GR_G = 1/t_G = (T_{c(G)} - T)/\theta_{T_c} \quad (2)$$

where θ_{T_c} is supra-optimal thermal time and $T_{c(G)}$ indicates that T_c values vary among different seed fractions (G) in the population. In this model, the variation in time for any fraction of the seed population to germinate is assumed to be the result of variation in their maximum temperatures ($T_{c(G)}$), and the total thermal time remained constant in the supra-optimal T range. Overall, the thermal time approach has been successful in describing germination time courses in response to T (Chantre et al., 2009; Hardegree, 2006), and most models predicting crop phenological development use a thermal time scale to normalize

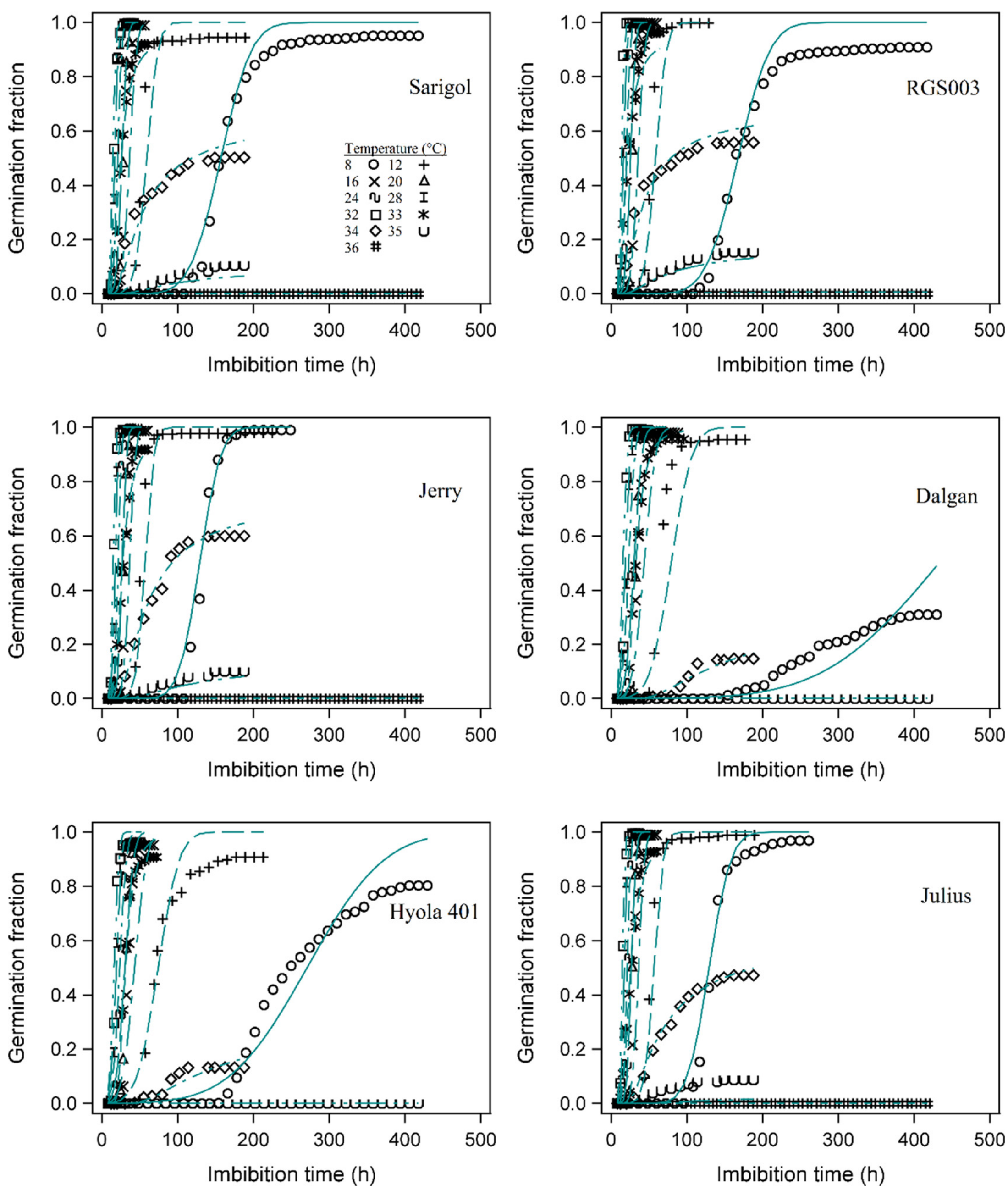

Fig. 1. Cumulative germination during time of six spring canola cultivars subjected to different constant temperature regimes. The symbols are the actual data, and the lines are the time courses predicted by the thermal-germination model.