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Relationships between Hydrotime Parameters and Seed Vigor in Sugar Beet

Salim Farzane • Elias Soltani*

Department of Agronomy and Plant Breeding, Islamic Azad University, Ardabil Branch, Ardabil 56157-31567, Iran

***Corresponding author*: * elias.soltani@yahoo.com**

ABSTRACT

The hydrotime concept is a unifying model to describe the patterns of germination that occur in response to the water potential (ψ) of a seed's environment. The question is, is there a relationship between the physiological status (i.e., hydrotime parameters) and early vigor? Four replicates were conducted, each consisting of 50 or 25 seeds (in a germination test and seedling growth, respectively) in which five cultivars ('IC', 'H5505', 'PP22', 'PP8', '7233' and 'BR1') of sugar beet seeds (*Beta vulgaris* L.) were germinated at five water potentials. Germination rate and final germination percentage were severely affected by reduced water potential in all cultivars. The predicted germination time courses at the various ψ and temperature values generally fitted well with the observed germination data by an R^2 value of 0.99 in all cultivars. The $\psi_{b(50)}$ varied between -1.30 and -1.67 MPa. $HT_{(50)}$ reduced from about 85 MPa°d to 100 MPa°d. There were significant differences among the six cultivars from five water potentials for germination rate and percentage, seedling dry weight and seedling length. Results indicated a correlation between germination traits and hydrotime model parameters. There was a significant relationship between base water potential and germination percentage (r = 90*) and rate (r = 0.81*), seedling dry weight (r = 0.89*) and seedling length (r = 0.85*). However, there was a non-significant relationship between hydrotime value and seed vigor parameters. Here, lower base water potential also contributed to high early vigor. Thus, plant breeding efforts or physiological remedies should be focused on improvement of cultivars with a lower base water potential.

Keywords: Hydrotime, base water potential, seed vigor; early vigor

INTRODUCTION

The hydrotime concept is a unifying model to describe the patterns of germination that occur in response to the water potential (ψ) of a seed's environment (Bradford 2004). It is similar to thermal time, or degree-days, in which the degrees in excess of a base or threshold temperature (Tb), multiplied by the time to a developmental event (for example, radicle emergence) is a constant (Bradford 2004). Gummerson (1986) proposed that in analogy with thermal time or degree-days responses in relation to temperature, the time to germination is related to the magnitude of the difference between the ψ of the seed or environment and the physiological ψ threshold for radicle emergence (ψb). Interestingly, Gummerson (1986) showed that in the case of germination responses to reduced ψ, the total hydrotime (MPa-hours or MPa-days) to radicle emergence was the same for all seeds in the population, but that individual seeds varied in their threshold ψ at which radicle emergence would be prevented. The following equation describes the basis of the hydrotime model (Bradford 1990, 1995):

$$HT = (\psi - \psi_{b(g)})t_g \quad (1)$$

where HT is the hydrotime constant (MPa day), ψ is the actual seed water potential (MPa), $\psi_b(g)$ is the base or threshold water potential (MPa) defined for a specific germination fraction g, and t_g is the time (day) to radicle emergence of fraction g of the seed population.

The advantage of this model is that it has parameters that are meaningful from a biological point of view, such as base water potential. Gummerson (1986) obtained a base water potential of sugar beet of about -1.70 MPa. Kebreab and Murdoch (1999) indicated that base water potential of *Orobanche aegyptiaca* varied between individual seeds according to a normal distribution with a mean of -1.96 and a standard deviation of 0.33 MPa at 20°C. Cheng and Bradford (1999) showed that the base water potential of tomato was between -0.66 and -0.87 MPa. Bradford (2004) explained that hydrotime analysis can be used to evaluate the physiological status of a seed lot and showed that broccoli lots of 1, 2, and 3 have similar hydrotime parameters and final germination percentages but the physiological status (i.e., hydrotime parameters) of seed lot 4, however, was distinctly different, and when planted under stressful conditions, this lot exhibited poor stand establishment and a relatively high frequency of abnormal seedlings.

It is well-known that early vigor might lead to increased yield potential by shorting the days from sowing to complete ground cover and a rapid increase in the establishment of an optimum canopy in wheat (Soltani *et al*. 2001, 2008). Optimum canopy establishment is required to minimize interplant competition and to maximize crop yield. López-Castañeda (1996) reported that some crop traits led to high early vigor: (1) a lower base temperature for growth, (2) greater shoot growth at the expense of root growth, (3) earlier germination, (4) more efficient utilization of seed reserves, (5) a greater embryo that gives rise to a larger shoot, and (6) larger leaf epidermal cells. The question is that is there a relation between the physiological status (i.e., hydrotime parameters) and early vigor? Before, Bradford (2004) showed that the primed seeds of lettuce germinated more rapidly than the control seeds. He concluded that this is due to a lower $\psi_{b(50)}$ value for the primed seeds, resulting in better germination at the lower ψ. However, there is no information showing the relationship between hydrotime parameters and early vigor. Therefore, the aims of this research were (1) to quantify seed germination of sugar beet in the response to water potential using hydrotime model and (2) to determine if there are any relationships between hydrotime parameters and seed vigor of sugar beet.

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MATERIALS AND METHODS

Seeds of sugar beet (*Beta vulgaris* L.) cultivars 'IC', 'H5505', 'PP22', 'PP8', '7233' and 'BR1' were obtained from the Sugar beet Seed Institute, Ardabil, Iran. The sizes of seeds were the same and seed viability of 95 %. Before experiments, seeds were washed by flowing water of 20°C for 3 h.

Germination test

Four replicates were conducted, each consisting of 50 seeds in which seeds were germinated at 5 water potentials: 0, -0.2, -0.4, -0.6 and -0.8 MPa. Water potentials were maintained by solutions of polyethylene glycol 6000 (Merck). Before seed placement, pleated filter papers were soaked in dishes containing an osmotic solution of desired water potential for 24 h. Seeds were observed twice daily and considered germinated when the radicle was approximately ≥2 mm long. Estimates of time taken for cumulative germination to reach 50% of its maximum at each replicate (D_{50}) were interpolated from the germination progress curve versus time. Germination rate (R_{50} h^{-1}) was then calculated according to Ellis *et al*. (1986) and Soltani *et al.* (2001, 2002):

$$R_{50} = 1/D_{50} \quad (2)$$

The following equation was used to hydrotime model (Gummerson 1986; Bradford 1990, 2002):

$$HT = (\psi - \psi_{b(g)})t_g \quad (3)$$

where HT is the hydrotime constant (MPa day), ψ is the actual seed water potential (MPa), $\psi_b(g)$ is the base or threshold water potential (MPa) defined for a specific germination fraction g, and t_g is the time (day) to radicle emergence of fraction g of the seed population. The model was fitted by SAS (SAS Institute Inc. 2000) using a non-linear fitting procedure.

Seedling growth

Four replicates were conducted, each consisting of 25 seeds for each cultivar in which seeds were germinated at 20°C. Seeds were placed on two moistened paper towels. After covering the seeds with a third sheet of paper, the three towels were loosely rolled to form a tube and placed in plastic bags (25 × 40 cm) to prevent evaporation. There were five water potentials as mentioned in the germination test. After 14 days, seedlings lengths were measured and Seedlings dry weights were determined, after oven-dried at 70°C for 48 h and weighed.

RESULTS AND DISCUSSION

Germination rate and final germination percentage were severely affected by reduced water potential in sugar beet (**Fig. 1; Table 1**). Cumulative germination percentage and fitted hydrotime model for each cultivar are presented in **Fig. 1**. The predicted germination time courses at the various ψ and temperature values generally fitted well with the observed germination data by R^2 value of 0.99 in all cultivars (**Table 1**). The estimated values of $\psi_{b(50)}$, $\sigma_{\psi b}$ and $HT_{(50)}$ differed in different cultivars (**Table 1**). The $\psi_{b(50)}$

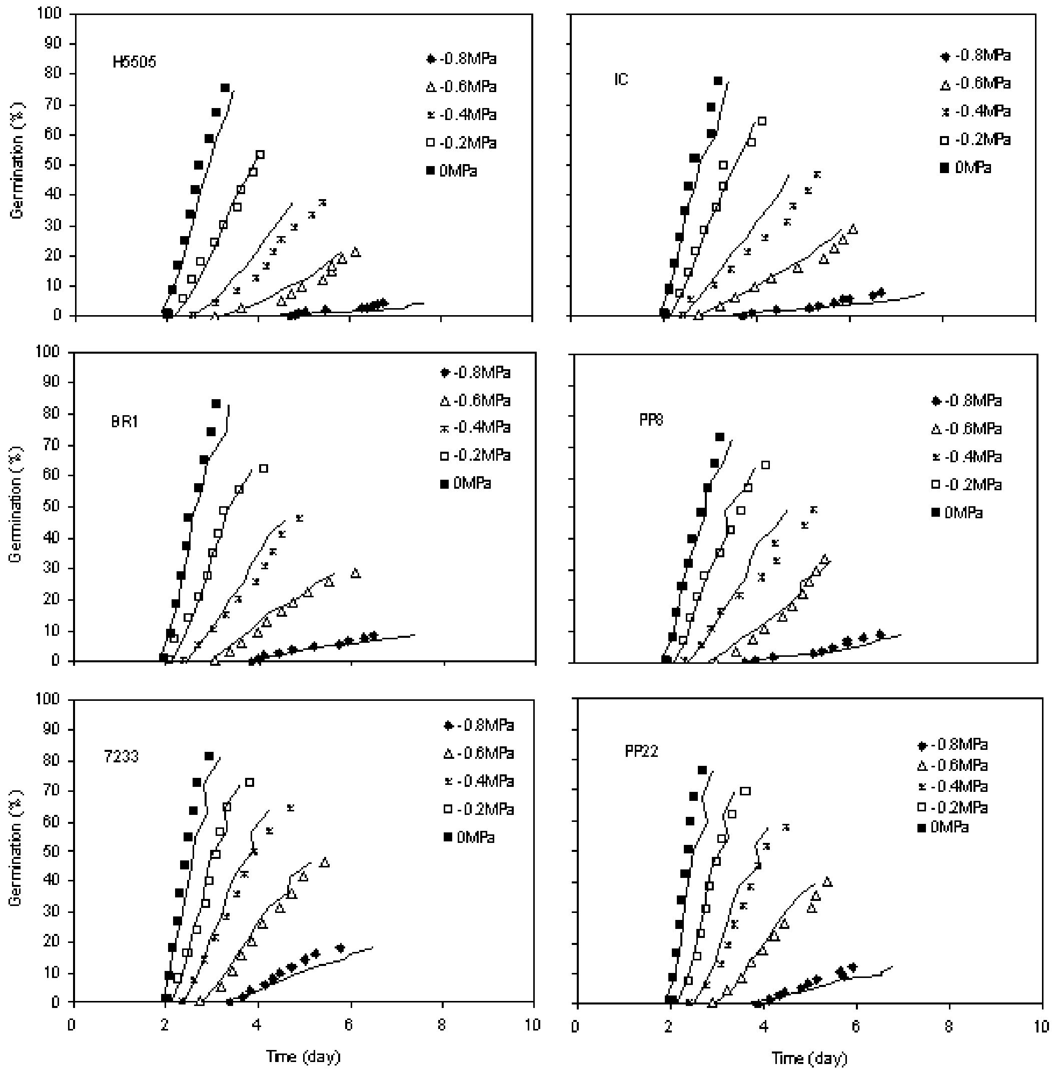

Fig. 1 Germination time courses for six sugar beet cultivars germinated at a range of water potentials. The symbols indicate the interpolation of observed germination data and the lines indicate the germination time courses predicted by the hydrotime model, based on parameter estimates in **Table 2**.

Table 1 Parameter estimates of the hydrotime model describing seed germination of six sugar beet cultivars at a range of water potentials. $\psi_{b(50)}$ is the median base water potential; $\sigma_{\psi b}$ is the standard deviation in base water potential; $HT_{(50)}$ is the hydrotime constant; R^2 is the coefficient of determination of the regression hydrotime model.

Cultivar	$\psi_{b(50)}$	$\sigma_{\psi b}$	$HT_{(50)}$	R^2
IC	-1.40	0.031	89.02 ± 10.192	0.99
H5505	-1.30	0.073	84.74 ± 7.842	0.99
PP22	-1.47	0.119	84.98 ± 7.502	0.99
PP8	-1.48	0.676	95.54 ± 11.937	0.99
7233	-1.67	0.134	99.68 ± 11.775	0.99
BR1	-1.53	0.176	95.85 ± 10.590	0.99

Table 2 Results of comparison of means (LSD) for germination percentage and rate, seedling dry weight, and seedling length in different cultivars.

Cultivar	Germination (%)	Germination rate (1/h)	Seedling dry weight (mg)	Seedling length (mm)
IC	50.00 c	0.0112 cd	16.53 ab	58.58 b
H5505	42.66 d	0.0106 d	10.86 c	46.66 c
PP22	56.93 b	0.0126 ab	14.40 b	57.06 b
PP8	50.80 c	0.0113 cd	13.06 bc	50.56 bc
7233	62.90 a	0.0127 a	19.33 a	68.20 a
BR1	50.93 c	0.0117 bc	14.93 b	58.57 b
LSD (0.05)	4.24	0.0009	3.16	9.93

Values with differences letter(s) are significant different at $P < 0.05$

varied between -1.30 ('H5505') and -1.67 (cv. '7233') MPa. $HT_{(50)}$ reduced from about 85 MPa °d (for 'H5505' and 'PP22') to 100 MPa °d (for 7233').

There were significant differences among the six cultivars from five water potentials for germination rate (range 0.011-0.013 1/h) and percentage (range 43-63 %), seedling dry weight (range 11-17 mg) and seedling length (range 47-68 mm) (**Table 2**). Maximum and minimum germination percentage and rate, seedling dry weight and seedling length were observed in '7233' and 'H5505', respectively. Results indicate a correlation between germination traits and hydrotime model parameters (**Fig. 2**). There was a significant relationship between base water potential and germination percentage (r = 90*) and rate (r = 0.81*), seedling dry weight (r = 0.89*) and seedling length (r = 0.85*). However, there was a non-significant relationship between hydrotime value and germination percentage (r = 0.54) and rate (r = 0.36), seedling dry weight (r = 0.54) and seedling length (r = 0.59) (data not shown).

Germination and seedling establishment are critical stages in a plant's life cycle. In crop production, stand establishment determines plant density, uniformity, and management options. For expensive hybrid vegetable and flower seeds, it is particularly important that seed germinate rapidly and uniformly, tolerate adverse germination conditions, and produce normal seedlings (Cheng and Bradford 1999). Gummerson (1986) developed a general model which combined thermal time and hydrotime models. There are many reports using these models to model seed germination and emergence (Bauer *et al*. 1998; Kebreab and Murdoch 1999; Masin *et al*. 2005; Windauer *et al*. 2007; Schutte *et al*. 2008). These reports are indicated **Table 3** in more details. Hydrotime analysis can provide several indices of seed quality relating to stress tolerance, speed and uniformity of germination (Bradford 2004). The hydrotime model proposes that the variation in germination timing of individual seeds at a given T is due to differences among seeds in their base or threshold ψ for radicle emergence ($\psi_{b(g)}$) (Gummerson 1986; Bradford 1990, 1995, 1997; Bloomberg *et al*. 2009; Watt *et al*. 2010). The difference between ψ and $\psi_{b(g)}$ multiplied by time to radicle emergence (t_g) is a constant (HT) for all seeds in the population. The hydrotime model worked well to characterize germination time-courses of six sugar beet lots at reduced ψ (**Fig. 1; Table 1**). The sensitivity of germination to ψ is influenced by the ψ at which seeds are incubated (**Fig. 1**). The median of the $\psi_{b(g)}$ distri-

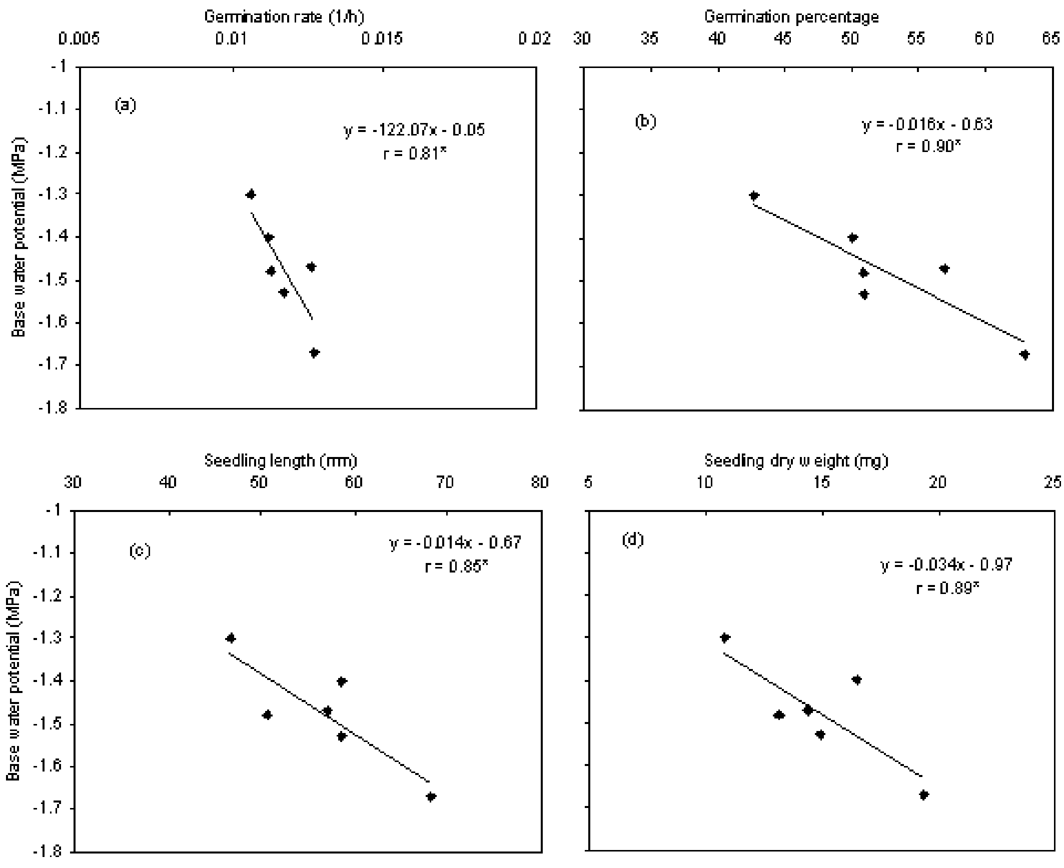

Fig. 2 Relationship between base water potential (MPa) and (a) germination rate, (b) germination percentage, (c) seedling length and (d) seedling dry weight in laboratory tests of seed germination and vigor for six sugar beet cultivars.

Table 3 Some reports using hidrotime models to model seed germination and emergence. Hidrotime and base water potential ($\psi_{b(g)}$) are indicated.

Researchers	Year	Species	Hidrotime	$\psi_{b(g)}$ (MPa)
Bauer *et al.*	1998	*Bromus tectorum* L.	22 – 52	(-1.27) – (+0.86)
Kebreab and Murdoch	1999	*Orobanche aegyptiaca*	3 – 16	(-2.08) – (-1.34)
Masin *et al.*	2005	Large crabgrass	-	-0.83
		Green foxtail	-	-0.70
		Goosegrass	-	-1.21
		Yellow foxtail	-	-0.69
Bair *et al.*	2006	*Bromus tectorum* L.	16 – 42	(-1.22) – (-0.80)
Windauer *et al.*	2007	*Lesquerella fendleri*	39 – 43	(-1.31) – (-0.92)
Schutte *et al.*	2008	*Ambrosia trifida*	-	(-10) – (-30)*

* for emergence

bution is therefore a physiological characteristic of a seed lot that can vary depending, for example, on seed dormancy or environmental conditions (Bradford 1995). The standard deviation of $\psi_{b(g)}$ ($\sigma_{\psi b}$), on the other hand, would be expected to remain fairly constant as it is the same seed population being tested under ψ condition, and in most cases $\sigma_{\psi b}$ varied relatively little between varieties (**Table 1**).

This study showed a relationship between base water potential and early vigor. López-Castañeda (1996) reported that a lower base temperature for growth led to high early vigor. Here, it was indicated that lower base water potential also contributed on high early vigor. Thus, plant breeding efforts or physiological remedies should focus on improvement of cultivars with a lower base water potential.

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