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Original Article

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PREDICTING SEED GERMINATION OF SAFFLOWER (*CARTHAMUS TINCTORIUS*) CULTIVARS USING HYDROTIME MODEL

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ABSTRACT. Safflower (*Carthamus tinctorius*) is a highly branched, herbaceous, thistle-like annual plant. It is commercially cultivated for vegetable oil extracted from the seeds, which is cultivated under arid environments. In such environments, the water needed for germination is available for only a short time and, consequently, successful crop establishment depends not only on rapid and uniform germination of the seedlot, but also on its ability to germinate under low water availability. All of these attributes can be analyzed through the hydrotime model (HT). Safflower seeds were germinated in various polyethylene glycol (PEG 600) solutions to obtain water potentials of 0, -0.2, -0.4, -0.6, and -0.8 Mpa. Results indicated that germination of safflower cultivars decreased significantly with reduction of osmotic potential. The highest germination percentage for Sina (93.06 and 94.02%), Faraman (93.52 and 95.33%), Talaei (94.98 and 93.98%) and Kouseh (93.58 and 95.55%) cultivars were attained from distilled water (0 MPa) and -0.2 MPa, respectively. The hydrotime constant (θ_H) for Sina, Faraman, Talaei and Kouseh cultivars were 0.93, 0.84, 0.78 and 0.72 MPa d, and the water potential ($\Psi_{b(50)}$) for Sina, Faraman, Talaei and Kouseh cultivars were -0.56, -0.67, -0.64 and -0.77 MPa, respectively. Cumulative germination of safflower seed was higher in Kouseh cultivar, than in Sina, Faraman and Talaei cultivars. Results showed that, hydrotime model is suited to predicting seed germination of safflower seeds. In addition, the information gathered with this work allows us to build mathematical models to predict germination of safflower cultivars in the field under various environments.

Keywords: germination percentage; germination rate; osmotic potential; safflower.

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INTRODUCTION

Seed germination and seedling emergence are a pivotal stages in the plant life cycle (Windauer *et al.*, 2012), which is mainly controlled by temperature and water (Bradford, 2002). The ability to predict the timing of germination of seeds and emergence of seedlings under a range of water regimes is useful for determining seeding date and subsequent seedling establishment success (Mesgaran *et al.,* 2013; Garcia *et al.,* 2013). Osmotic potential is a very important factor controlling seed germination, affecting both the rate and final percentage of germination (Ansari *et al.,* 2012).

Generally, germination rate (GR) increases linearly with water availability (Gummerson, 1986; Bradford, 1990; Dahal and Bradford, 1990) and germination percentage is reduced at reduced water potential (Grundy *et al.,* 2000; Kebreab and Murdoch, 2000). Meanwhile, water has more complicated effects on germination than temperature, especially at low water potential.

Various germination models have been used to describe seed germination, specifically, the hydrotime model describes seed germination responses to water potential changes using the following function (Gummerson, 1986; Bradford, 1990):

$$\theta_H = (\psi - \psi_{b(g)}) \times t_g \qquad \text{(Eqn 1)},$$

where θ_H is the hydrotime (MPa h) of the seeds require for germination, ψ is the actual water potential of the germination medium (MPa), $\psi_{b(g)}$ is the theoretical threshold or base water potential that will just prevent germination of fraction *g*, and t_g is the germination time (h) of the corresponding fraction *g*. The model assumes that ψ_b varies among fractions of a seed population, following a normal distribution with its mean, $\psi_{b(50)}$, and standard deviation, $\sigma_{\psi b}$, and θ_H is considered constant for a seed population (Bradford, 1990). The assumptions allow the germination time-course curve for a seed population to be characterized by the following probit equation:

$$\text{Probit}(g) = (\psi - \theta_H/tg) - \psi_{b(50)}/\sigma_{\psi b} \qquad \text{(Eqn 2)}$$

The parameters of the model have proven to have a physiological basis and an ecological significance (Bradford, 2002); therefore, these modelling approaches have been successful in prediction of field seedling emergence (Roman *et al.,* 2000).

Safflower (*Carthamus tinctorius*) is a highly branched, herbaceous, thistle-like annual plant. It is commercially cultivated for vegetable oil extracted from the seeds. Plants are 30 to 150 cm (12 to 59 in) tall with globular flower heads having yellow, orange or red flowers. Each branch will usually have from one to five flower heads containing 15 to 20 seeds per head. Safflower is native to arid environments having seasonal rain. It grows a deep taproot which enables it to thrive in such environments. Safflower is a plant resistant to drought and salinity stress and having to types of spring and fall has a promising future. Safflower yield, as other agricultural products, is influenced by different factors, such as genotype, planting date, compression, humidity and soil fertility, temperature and light.

The purpose of this research was to determine: 1) seed germination and germination rate of four safflower cultivars, under osmotic potential conditions using functional three-parameter sigmoidal model; 2) predicting seed germination of four safflower cultivars using hydrotime model.

MATERIAL AND METHODS

This study was conducted in the Faculty and Agricultural and Natural Resources Research Center of Yazd, Iran.

Germination protocol. Twenty five seeds of safflower were placed evenly in a Petri dish (9 cm diameter) containing two pieces of No.1 filter paper. The filter paper was moistened with 5 ml deionized water (pH=6) and other with polyethylene glicol test solution. The Petri dishes were placed in an incubator at 25°C, under constant darkness, for 14 days. The number of seeds that germinated was determined after 14 days.

Effect of osmotic potential. Safflower seeds were germinated in various polyethylene glycol (PEG 600) solutions to obtain water potentials of 0, -0.2, -0.4, -0.6 and -0.8 Mpa (Michel and Kafman). Other environmental conditions were the same as previously stated in the germination protocol.

Statistical analysis. A randomized complete block design with three replications was used in this experiment and were analyzed by means of regression analysis using the SigmaPlot 11 software. The germination percentage value obtained at different osmotic stress were fitted to a functional three-parameter sigmoidal model of the form Eqn 3.

$$G= a/(1+\exp(-(x-x_{50})/b)) \quad \text{(Eqn 3)},$$

where G is the total seed germination percentage, *a* is the maximum seed germination percentage for different osmotic stress, x_{50} is the osmotic to reach 50% of maximum seed germination and *b* is the slope of the curve or lag phase.

Data analyses to determine the values of the hydrotime model parameters; $\psi_{b(50)}$, θ_H, and $\sigma_{\psi b}$ were conducted using repeated probit regression analysis as described previously (Eqn 2) by Bradford (1990, 2002).

RESULTS AND DISCUSSION

The cumulative germination curves at each osmotic potential and cultivar were modelled by the three-parameter sigmoidal function (*Fig. 1*). Results indicated that germination of Safflower cultivars decreased significantly with reduction of osmotic potential (*Fig. 1, Table 1*). The highest germination percentage for Sina (93.06 and 94.02%), Faraman (93.52 and 95.33%), Talaei (94.98 and 93.98%) and Kouseh (93.58 and 95.55%) cultivars were attained from distilled water (0 MPa) and -0.2 MPa, respectively *(Fig. 1, Table 1)*. The minimum X_{50} for Sina (1.88 d), Faraman (1.82), Talaei (1.84 d) and Kouseh (1.73 d) cultivars were attained from distilled water (0 MPa) (*Table 1*).

In general, results indicated that germination percentage (G_{max}) and germination rate ($1/X_{50}$) reduced as a result of water potential increment (*Table 1*). The hydrotime constant (θ_H) for Sina, Faraman, Talaei and Kouseh cultivars were 0.93, 0.84, 0.78 and 0.72 MPa d (*Table 2*), and the water potential ($\Psi_{b(50)}$) for Sina, Faraman, Talaei and Kouseh cultivars were -0.56, -0.67, -0.64 and -0.77 MPa, respectively (*Table 2, Fig 5*). In most cases, the model fitted the experimental data well with R^2 values ranging from 0.84 to 0.89 (*Figs. 2 and 3*). Cumulative germination percentage at different osmotic potentials (Mpa), versus normalized for safflower cultivars seeds is presented in *Fig. 4*.

In general, water potential influenced germination rate and final germination percentage in safflower seeds. The interactive effect of water potential on germination rate and percentage of safflower has also been reported in other species (Kebreab and Murdoch, 1999; Ebrahimi and Eslami 2012; Nandula *et al.,* 2006; Bolfrey-Arku *et al.,* 2011).

These results suggest that the Kouseh cultivar should have better performance than the Sina, Faraman and Talaei cultivars, under field conditions. The germination of safflower seeds, as many other species, is tolerant to decreasing values of Ψ in the medium.

Germination is basic processes in the survival and success of a plant (Bradford, 2002; Ansari *et al.,* 2012) and the ability to predict germination could enhance crop management. In fact, this distribution has been almost exclusively assumed so far in hydrothermal models (Gummerson, 1986; Bradford, 1990). Nevertheless, it has been recently shown that alternative functions that allow for a rightskewed distribution of Ψ_b (g), such as the log-logistic, inverse normal or lognormal distributions, depending on the species, can provide a more accurate fit to germination data (Mesgaran *et al.,* 2013). Karlsson and Milberg (2007) found a good fit for *C. bonariensis* germination data with the logistic function, the possibility remains that alternative functions might give better fit. However, various researchers have utilized normally-distributed hydrotime model to estimate hydrotime constant, base water potential and standard deviation for different plant seed species (Windauer *et al.,* 2006; Mesgaran *et al.,* 2013; Huarte, 2006).

This study indicates that safflower seed is tolerant to osmotic potential. In contrast, these data show that germination of safflower remains high under osmotic potential conditions and may have a competitive advantage, over against other plant and weed species under drought stress conditions.

Table 1 - Estimated parameters by fitting three-parameter sigmoidal model to cumulative germination percentage of safflower cultivars in response to different osmotic potentials. Numbers in parentheses represent standard error.

Cultivar	Osmotic potential (Mpa)	Parameters			
		a (G_{max})	*b* (d)	X_{50} (d)	R^2
Faraman	0	93.52(0.89)	0.69(0.06)	1.82(0.6)	0.99
	-0.2	95.33(2.08)	1.27(0.17)	2.51(0.18)	0.97
	-0.4	70.34(0.97)	1.11(1.00)	2.54(0.11)	0.99
	-0.6	50.78(0.98)	1.92(0.15)	4.16(0.16)	0.99
	-0.8	50.41(1.79)	1.88(0.19)	6.83(0.25)	0.99
Sina	0	93.06(0.94)	0.77(0.06)	1.88(0.07)	0.99
	-0.2	94.02(1.86)	1.30(0.15)	2.61(0.17)	0.97
	-0.4	68.17(0.96)	1.38(0.11)	3.08(0.12)	0.99
	-0.6	50.21(1.08)	2.11(0.15)	4.88(0.18)	0.99
	-0.8	41.28(0.89)	1.81(0.11)	6.93(0.15)	0.99
Talaie	0	94.98(0.90)	0.70(0.06)	1.84(0.06)	0.99
	-0.2	93.98(1.75)	1.33(0.15)	2.69(0.16)	0.98
	-0.4	68.79(1.12)	1.27(0.12)	2.65(0.13)	0.98
	-0.6	52.14(1.26)	2.04(0.19)	4.13(0.21)	0.99
	-0.8	38.53(1.37)	1.44(0.21)	5.86(0.25)	0.98
Kouseh	0	93.58(1.03)	0.72(0.07)	1.73(0.08)	0.99
	-0.2	95.55(2.29)	1.33(0.19)	2.44(0.20)	0.96
	-0.4	74.02(1.29)	1.05(0.12)	2.31(0.14)	0.98
	-0.6	60.26(0.93)	1.18(0.11)	2.85(0.12)	0.99
	-0.8	53.47(1.79)	1.25(0.20)	5.53(0.23)	0.98

Table 2 - Estimated parameters of hydrotime model for safflower cultivars. θ_H, $\Psi_{b(50)}$ and $\sigma_{\Psi b(50)}$ indicate, respectively, hydrotime constant, mean base water potential and its standard deviation in safflower cultivars population. Numbers in parentheses represent standard error.

Culivar	θ_H	$\Psi_{b(50)}$	$\sigma_{\Psi b(50)}$	R^2
Sina	0.93(0.07)	-0.56(0.03)	0.36(0.03)	0.87
Faraman	0.84(0.08)	-0.67(0.03)	0.41(0.03)	0.85
Talaei	0.78(0.08)	-0.64(0.03)	0.38(0.03)	0.85
Kouseh	0.72(0.11)	-0.77(0.05)	0.47(0.05)	0.84

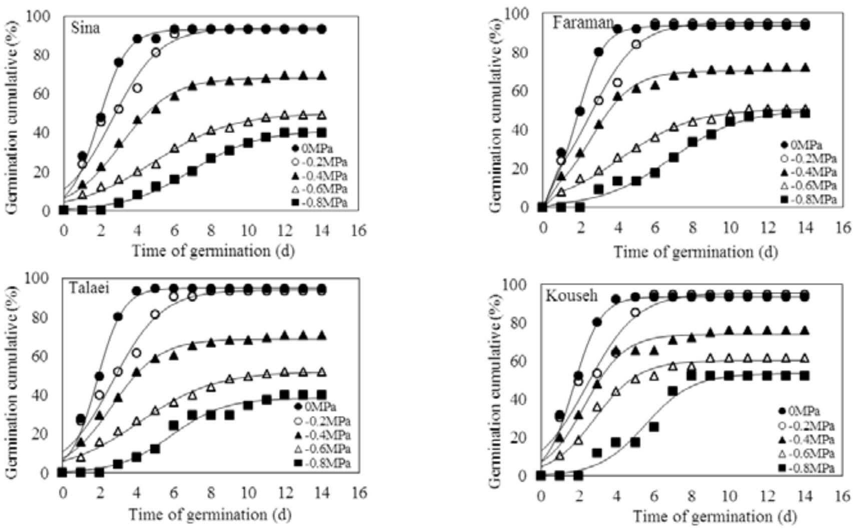

Figure 1- Fitting three-parameter sigmoidal model to cumulative germination percentage of safflower cultivars in response to time in different osmotic potentials

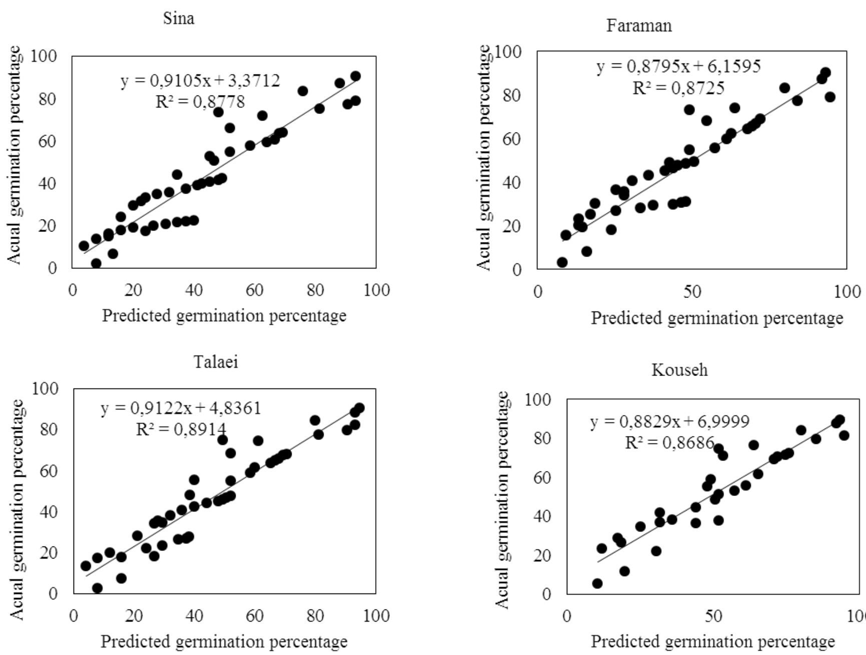

Figure 2 - Injective function of observed germination percentage values versus predicted values from hydrotime model in different temperatures for safflower cultivars

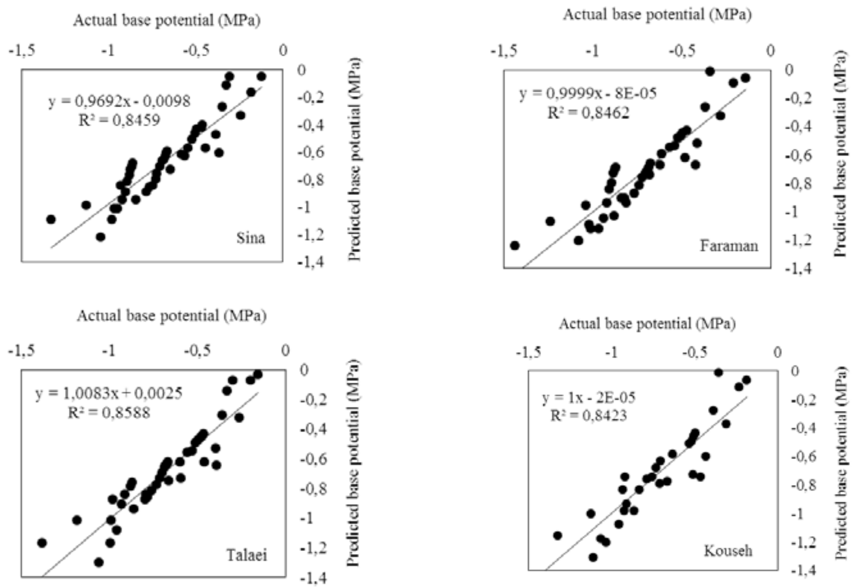

Figure 3 - Predicted base water potential values from hydro time model versus observed values (MPa) for safflower cultivars

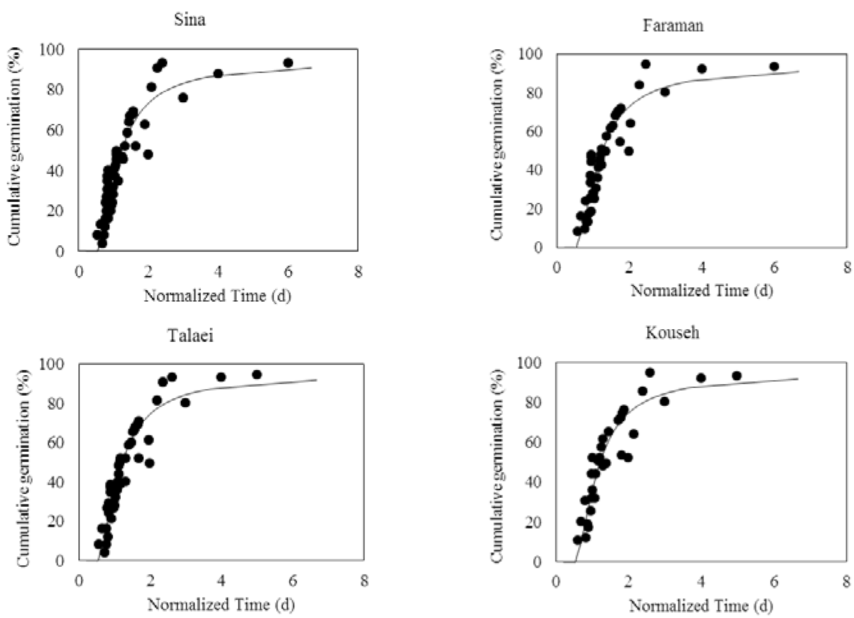

Figure 4 - Cumulative germination percentage at different osmotic potentials (Mpa) versus normalized for safflower cultivars seeds

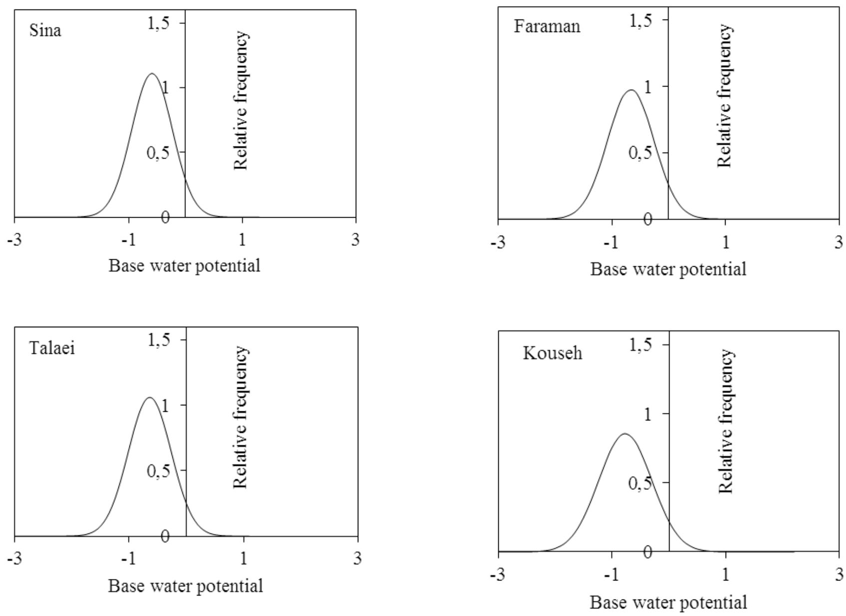

Figure 5 - Normal distribution of base water potential (MPa) for safflower cultivars population

CONCLUSION

Cumulative germination of safflower seed was higher in Kouseh cultivar than in Sina, Faraman and Talaei cultivars. Germination percentage and germination rate could occur under a wide potential osmotic, although it is concentrated in the Kouseh cultivar. Results showed that hydrotime model is suited to predicting seed germination of safflower seeds. In addition, the information gathered with this work allows us to build mathematical models to predict germination of safflower cultivars in the field under various environments.

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