RESEARCH PAPER

Effects of the sowing depth and temperature on the seedling emergence and early growth of wild barley (*Hordeum spontaneum*) and wheat

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The experiment was conducted under a controlled environment to study the effects of different temperature regimes (15/10°C, 20/15°C, and 25/20°C day/night) and sowing depths (0, 2, 4, and 6 cm) on the seedling emergence and early growth (height gain) of wheat (cv. Marvdasht) and wild barley (*Hordeum spontaneum*). The cumulative emergence and plant height gain over time were modeled with the use of a logistic function. For a particular temperature regime, the maximum percentage emergence (E_{max}) of wheat was higher than that of wild barley across all sowing depths. The maximum and minimum E_{max} values for both species occurred at 20/15°C and 25/20°C, respectively. The time taken to reach 50% of the E_{max} (i.e., E_{50}) increased with the sowing depth in both species under all temperature regimes. The E_{50} of wild barley was greater than that of wheat for all temperature regimes, with maximum differences observed at 20/15°C. The greatest maximum plant height (H_{max}) was observed at the surface planting for both plants. The H_{max} was reduced at temperatures either lower or higher than 20/15°C, with a more notable reduction in wild barley. At all temperature regimes, the time taken to reach 50% of the H_{max} (i.e., H_{50}) increased linearly with the sowing depth but, at higher temperatures, the accelerated growth rate reduced the H_{50}. The wild barley seedling emergence and height gain rate, as expressed relative to those of wheat, revealed the highest superiority of wheat over wild barley at 25/20°C and the sowing depth of 4 cm.

Keywords: early growth, seedling emergence, sowing depth, temperature.

Wild barley (*Hordeum spontaneum* [C. Koch] Thell.) grows in diverse habitats in the eastern Mediterranean and in south-western Asia (Gutterman *et al.* 1996) and is widely distributed in the winter fields of Iran. Based on recent weed surveys, it is now present in >16 provinces in Iran and is increasing in its abundance in winter wheat fields (Baghestani *et al.* 2007). Wild barley is a progenitor of cultivated barley (*H. vulgare* L.) (Harlan & Zohary 1966) and, due to its close morphological and physiological similarities to wheat crops, selective herbicides for its control are not available (Baghestani *et al.* 2007); however, it is considered to be a weed of economic importance in wheat crops. For example, it has caused a 38% reduction in the wheat grain yield when grown at 80 plants m^{-2} in competition with wheat (Hamidi 2006). Hamidi also reported the allelopathic effect of both the shoot and seed extract of this species on seed germination and the shoot and root length of wheat seedlings.

Integrated weed management systems require a comprehensive knowledge of weed biology (Buhler 1999). Seedling emergence is a crucial stage in the life cycle of annual weeds whose regeneration solely depends on seed. The time of weed emergence relative to that of a crop can markedly affect subsequent crop–weed competition (Zimdahl 1980). For example, weed seedlings that emerge after the crop will interfere poorly and will then produce fewer seeds than those emerging before or with

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the crop (Cousens & Mortimer 1995). However, the most competitive weeds appear to be those that are the earliest to emerge and the timing of the emergence of a seedling population is more important than the spatial arrangement of the seedling in determining resource utilization (Radosevich et al. 1997). Gan et al. (1992) reported that the wheat plants that emerged early contributed more towards the crop yield than those that emerged later. In addition to rapid germination and emergence, early above-ground growth and greater plant height are among the traits commonly identified as making crops more competitive (Beheshtian-Mesgaran et al. 2006). The importance of plant height to competitiveness also was demonstrated in studies of competition between velvetleaf (Abutilon theophrasti) and soybean (Akey et al. 1990), wild oat (Avena fatua) and wheat (Cudney et al. 1991), and eastern black nightshade (Solanum ptycanthum) and processing tomato (McGiffen et al. 1992).

Both seedling emergence and early growth could be influenced by various factors, such as the position of seeds in the soil profile (burial depth) and temperature (Cousens & Mortimer 1995). Knowledge of the weed/crop emergence response to temperature has practical implications in selecting the proper crop sowing date under which a crop would take some advantage over the weeds; for example, by expressing the time taken till the 50% emergence of each weed relative to the crop. Weaver et al. (1988) predicted the optimum sowing temperature under which a tomato crop would emerge furthest ahead of its main weeds and, therefore, experience the least interference. However, the way in which land is prepared for crop sowing will determine the distribution of weed seeds in the soil profile (Cousens & Moss 1990) and, therefore, the subsequent seedling emergence pattern. However, the weed species (and crops) vary in their response to the sowing depth. Campsis radicans emergence was maximum (68%) for seeds that were placed on the soil surface, but no seedling emerged from the soil depth of 4 cm (Chachalis & Reddy 2000). On the contrary, no seedlings of threehorn bedstraw (Galium tricornutum) emerged from seeds placed on the surface (0 cm) (Chauhan et al. 2006). Limited soil-to-seed contact, light conditions on the surface, and water availability are some environmental factors that may limit the germination of some seeds on the soil surface (Ghorbani et al. 1999). The decreasing trend in seedling emergence with the increasing sowing depth (Chachalis & Reddy 2000), however, was attributed to the limited carbohydrate reserves (Mennan & Ngouajio 2006; Thomas et al. 2006). Thus, whether a tillage system or other seedbed preparation operations could effectively control weeds is highly dependent on the weed-specific emergence response to the burial depth.

Although the effects of the sowing depth and temperature on seedling emergence have been studied for many weed species and crops (Weaver et al. 1988; Andrews et al. 1991; Ghorbani et al. 1999; Chachalis & Reddy 2000; Chauhan et al. 2006), no study has examined these effects on a weed’s or crop’s early growth, an attribute once mentioned to have a deterministic effect on weed–crop competition output (Beheshtian-Mesgaran et al. 2006). Furthermore, comparing the seedling emergence and early growth of a crop with those of its main weed(s) under the influence of various sowing depths and temperature regimes rarely have been studied and no studies exist for a wheat–wild barley complex. Thus, the objectives of this study were: (i) to examine the effect of the sowing depth on the seedling emergence and early growth (in terms of plant height gain) of a wheat crop and wild barley; (ii) to compare the response of wheat and wild barley to the above treatments; and (iii) to determine whether the seedling emergence and early growth attributes would respond to treatments similarly. The findings of this experiment contribute to improving the integrated management of wild barley in wheat by providing some predictions about the situation(s) under which a wheat crop could acquire a relative superiority over wild barley.

MATERIALS AND METHODS

The laboratory experiment was conducted in 2006 at the campus of Agricultural and Natural Resource Science, University of Tehran, Karaj, Iran. Wild barley caryopses (hereafter, referred to as seeds) were harvested at maturity from infested wheat fields at Zarghan, Fars Province, in 2004. The seeds were stored dry at room temperature until the beginning of the experiment. A primary germination test showed >98% germination for both wild barley and wheat (cv. Marvdasht; Seed and Plant Breeding Institute, Karaj, Iran).

Then, 10 cm-diameter pots were filled with a growing medium consisting of a 2:1 mixture of a clay loam soil (35% clay, 28% sand, 37% silt, and 1.8% organic matter) and manure. The soil and manure were passed through a 5 mm sieve to remove all the bulk particles. Twelve seeds of wild barley (or wheat) were placed equidistantly on the soil surface (growing medium) or covered to depths of 2, 4, and 6 cm with the same soil. The seeds on the soil surface were covered with moistened filter paper to stimulate imbibition (Benvenuti et al. 2001). The pots were surface-irrigated and care was taken not to move...
the seeds sown on the surface. The pots were transferred to a growth cabinet and three alternating temperature regimes of 15/10, 20/15, and 25/20°C (day/night) were tested. Although these temperature regimes do not completely reflect the temperature fluctuations at Fars Province, where the wild barley is a main constraint to wheat production, they somewhat mimic the range of temperatures that might be encountered in fall by a late (15/10°C) to early (25/20°C) planting date. The high temperature component of the regime was maintained for 14 h. Light was provided by fluorescent lamps set for a 14 h light/10 h dark regime, with an intensity of 200 μmol m⁻² m⁻¹. Daily emergence counts were made for 19 days. The plants were considered to have emerged when a 1 cm leaf tip could be visibly discerned. Early growth was described in terms of plant height gain, as the importance of this attribute was highlighted previously. From each pot, the first four emerging seedlings were marked and their height (from the soil level to the leaf tip) was measured daily for 19 days.

Statistical analysis

The experiment was a completely randomized design with a factorial arrangement of treatments (i.e. two plants species × four sowing depths × three temperature regimes). Each treatment was replicated four times. Cumulative emergence was regressed against time using a three-parameter logistic function (Knezevic et al. 2007):

\[ E_t = \frac{E_{\text{max}}}{1 + \left( \frac{T}{E_{50}} \right)^b} \]  

where \( E_t \) is the cumulative percentage emergence at time \( T \), \( E_{\text{max}} \) is the asymptote or theoretical maximum for \( E_t \), \( E_{50} \) is the elapsed time (days) to reach 50% of the maximum emergence (\( E_{\text{max}} \)), and the parameter, \( b \), is the relative slope around \( E_{50} \), that is, the inflection point, and denotes the rate of increase in emergence. The interpretation of these parameters is discussed in detail by Streibig et al. (1993). The same model was also fit to the plant height data:

\[ H_t = \frac{H_{\text{max}}}{1 + \left( \frac{T}{H_{50}} \right)^b} \]  

where \( H_t \) is the plant height (cm) at time \( T \), \( H_{\text{max}} \) is the maximum plant height, \( H_{50} \) describes the number of days to reach 50% of the final plant height (\( H_{\text{max}} \)), and \( b \) is the slope around \( H_{50} \). The \( E_{\text{max}} \) (or \( H_{\text{max}} \)) and \( E_{50} \) (or \( H_{50} \)) parameters that are biologically more meaningful and describe the total emergence (or final plant height) and emergence rate (or growth rate) are discussed.

and second order polynomial functions were further used to describe the main effect of the sowing depth on the above parameter estimates. All the models were fit using SigmaPlot’s (2000) (Sigma plot 10.0 software, Sigma Plot 2002 for Windows Version 8.0, SPSS Inc., 233 South Wacker Dr., Chicago, IL 60606.) statistical package. The data showed a homogenous variance distribution and satisfied the tests of normality; thus, no transformation was made.

RESULTS AND DISCUSSION

Seedling emergence parameters

\( E_{\text{max}} \) response

The logistic function fitted well to seedling emergence (and height gain data), with a coefficient of determination \( R^2 \) that exceeded 0.95 for all the datasets (data not shown). The sowing depth and temperature regime interacted to affect the estimated \( E_{\text{max}} \) values (Fig. 1). Wild barley and wheat differed in their response to the treatments. For a particular temperature regime, the \( E_{\text{max}} \) value of wheat was higher than that of wild barley at all sowing depths (Fig. 1). Under all temperature regimes, the \( E_{\text{max}} \) value of wild barley declined drastically with the sowing depth. However, the greatest \( E_{\text{max}} \) value (96.2%) for wild barley was observed at 15/10°C and the sowing depth of 2 cm. Wheat was less sensitive to the sowing depth compared with wild barley, particularly at 20/15°C, where no reduction in the \( E_{\text{max}} \) value was observed at sowing depths ≤4 cm. The greatest difference between the \( E_{\text{max}} \) value of wheat and that of wild barley occurred at 25/20°C. At this temperature regime and when sown to a depth of 2 cm, the wheat seedling emergence was 75% greater than that of wild barley. None of the species emerged from the sowing depth of 6 cm at 25/20°C (Fig. 1). An inspection of the soil showed that most of the seeds that were exposed to this treatment had germinated but had failed to reach the soil surface during the 19 days of seedling enumeration. Thus, the failure in emergence was not related to germination failure but to a very slow emergence rate. However, in the study of Benvenuti et al. (2001), the examination of the seeds recovered from the burial depth at which none of them succeeded in emerging showed that almost all the seeds remained completely dormant, so that germination was very limited in their study. It was not possible to continue the seedling enumeration and plant height measurements for a longer time because of our growth cabinet height limitation. Nineteen days following the initiation of the experiment, some plants (from some particular treatments) reached their maximum allowable height, but were not able to grow taller due to the space limitation.
Regardless of the temperature treatments, the $E_{\text{max}}$ value for both wheat and wild barley decreased with the sowing depth, following a quadratic trend (Fig. 2a). There was an overall agreement that the emergence inhibition increases proportionally with the depth of seed burial in the soil (Andrews et al. 1991; Benvenuti & Macchia 1997; Chachalis & Reddy 2000; Benvenuti et al. 2001). When sown on the soil surface, the wheat and wild barley $E_{\text{max}}$ values were 97% and 79%, respectively. This 18% greater emergence observed for wheat at surface planting remained consistent across all the other sowing depths (Fig. 2a). The optimum depth of seedling emergence for wheat and wild barley were 1.3 and 0.13 cm, respectively (Fig. 2a). Thomas et al. (2006) and Ghorbani et al. (1999) reported a favorable effect of shallow burial (~0.5–1 cm) on the emergence of other species. For all the temperature regimes, the $E_{\text{max}}$ values of wheat were always greater than those of wild barley. For both species, the minimum and maximum $E_{\text{max}}$ values occurred at 25/20°C and 20/15°C, respectively (Fig. 2b). Over the wide range of constant temperatures tested by Singh and Dhaliwal (1972), the greatest seedling emergence for wheat sown as deep as 2.5 cm was observed at 20°C and 25°C. Hamidi (2006) also reported the constant temperatures of 20°C and 25°C as the optimum temperatures for wild barley and wheat germination, respectively, but did not test the seedling emergence response.
**E₅₀ response**

For both plants, the number of days to reach 50% of the maximum cumulative emergence (E₅₀), which is an indication of the emergence rate, increased progressively as the seeds were sown deeper (Fig. 3). Similarly, the mean emergence time for 20 weed species tested by Benvenuti et al. (2001) increased markedly as the burial depth increased. The delay in emergence from deeper soil levels means that deeply buried seeds have a disadvantage in competition with crops (Cousens & Mortimer 1995; Radosevich et al. 1997; Benvenuti et al. 2001). In total, the rapidity of emergence (described by lower E₅₀ values) was greater for wheat compared with wild barley, particularly at surface planting. However, both species responded similarly to the sowing depths at 25/20°C (Fig. 3).

Over all the temperature regimes, the highest emergence rate (i.e. lowest E₅₀ value) occurred at surface planting, with E₅₀ values of 3.2 and 5.5 days for wheat and wild barley, respectively. However, the E₅₀ value of both plants increased (i.e. a delay in emergence) linearly as the sowing depth increased from 0–6 cm (Fig. 4a). At the sowing depth of 6 cm, both wheat and wild barley required 12 days to reach 50% of their corresponding E₅₀ value. Although there was no difference between wheat and wild barley in the E₅₀ value, both within and

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**Fig. 3.** Effect of the alternating temperature regimes and sowing depths on the E₅₀ parameter (number of days to reach 50% of the maximum emergence), as estimated with the use of the logistic function (Eqn 1): Eₜ = E₅₀/1 + (T/E₅₀)^b. The vertical bars indicate the standard error of the estimated parameter. Note that no seedling emerged during the 19 days of enumeration at 25/20°C and a sowing depth of 6 cm (shown by the dotted line). (●), wild barley; (○), wheat.

**Fig. 4.** Main effect of the (a) sowing depths and (b) alternating temperature regimes on the E₅₀ parameter (number of days to reach 50% of the maximum emergence), as estimated with the use of the logistic function (Eqn 1): Eₜ = E₅₀/1 + (T/E₅₀)^b. The vertical bars indicate the standard error of the estimated parameter. (●), wild barley; (○), wheat.

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between the temperature regimes of 15/10°C and 20/15°C, the E50 value decreased significantly for both species at 25/20°C (Fig. 4b).

Height gain parameters

\( H_{\text{max}} \) response

The sowing depth by temperature regime interaction for the \( H_{\text{max}} \) parameter is depicted in Fig. 5. With the exception of 20/15°C, where the sowing depth had no significant effect on the \( H_{\text{max}} \) value, at the two other temperature regimes (15/10°C and 25/20°C), it decreased drastically with an increasing sowing depth. The magnitude of the reduction in the \( H_{\text{max}} \) value was more profound for wild barley than that of the wheat crop. In the case of wheat, these results were in agreement with the \( E_{\text{max}} \) response to the temperature by sowing depth interaction effects. Here, the sowing depth effect on the \( E_{\text{max}} \) value at 20/15°C was less noticeable than for other thermal treatments (Fig. 1). Both wheat and wild barley had a similar maximum height (19 cm) when sown on the surface, but wild barley was more susceptible to the sowing depth (Fig. 6a); that is, while there was an inversely linear relationship between the \( H_{\text{max}} \) value and the sowing depth for wild barley, that of

**Fig. 5.** Effect of the alternating temperature regimes and sowing depths on the \( H_{\text{max}} \) parameter (maximum plant height), as estimated with the use of the logistic function (Eqn 2): \( H_t = H_{\text{max}}/1 + (T/H_{50})^b \). The vertical bars indicate the standard error of the estimated parameter. Note that no seedling emerged during the 19 days of enumeration at 25/20°C and a sowing depth of 6 cm (shown by the dotted line). (○), wild barley; (○), wheat.

**Fig. 6.** Main effect of the (a) sowing depths and (b) alternating temperature regimes on the \( H_{\text{max}} \) parameter (maximum plant height), as estimated with the use of the logistic function (Eqn 2): \( H_t = H_{\text{max}}/1 + (T/H_{50})^b \). The vertical bars indicate the standard error of the estimated parameter. (●), wild barley; (○), wheat.
the wheat crop showed a quadratic polynomial response: its \( H_{\text{max}} \) value declined gradually. Each unit of increase in the sowing depth reduced the \( H_{\text{max}} \) value of wild barley by 1.9 cm (estimated based on the slope of inverse linear regression; Fig. 6a).

The plants grown at temperature regimes either lower or higher than the median temperature of 20/15°C were shorter in height (having lower \( H_{\text{max}} \) values), with more pronounced retardant effects on wild barley (Fig. 6b).

\( H_{50} \) response

For all the temperature regimes, the deeper planting increased the time taken to reach the 50% final height (i.e. \( H_{50} \)) (Fig. 7). Wild barley and wheat responded to the sowing depth in the same manner at the temperature regimes of 15/10 and 25/20°C. However, at the median temperature (20/15°C), the wild barley seedlings that emerged from the depths of 4 or 6 cm had significantly higher \( H_{50} \) values than wheat (Fig. 7). There was no significant difference between wild barley and wheat in terms of their \( H_{50} \) responses to the sowing depth treatments (Fig. 8a). Averaged over all the temperature regimes, increasing the sowing depth from 0–6 cm increased the \( H_{50} \) of both plants from 6–13.3 days (Fig. 8a).

In contrast to the sowing depth, increasing the temperature had progressive effects on the growth rate.

\[
H_t = \frac{H_{\text{max}}}{1 + \left( \frac{T}{H_{50}} \right)^b}.
\]

The vertical bars indicate the standard error of the estimated parameter. Note that no seedling emerged during the 19 days of enumeration at 25/20°C and a sowing depth of 6 cm (shown by the dotted line). (●), wild barley; (○), wheat.

**Fig. 7.** Effect of the alternating temperature regimes and sowing depths on the \( H_{50} \) parameter (number of days to reach 50% of the final plant height), as estimated with the use of the logistic function (Eqn 2): \( H_t = \frac{H_{\text{max}}}{1 + \left( \frac{T}{H_{50}} \right)^b} \). The vertical bars indicate the standard error of the estimated parameter. Note that no seedling emerged during the 19 days of enumeration at 25/20°C and a sowing depth of 6 cm (shown by the dotted line). (●), wild barley; (○), wheat.

\[
Y(\text{wheat}) = 1.0901x + 6.09 \ (R^2 = 0.96)
Y(\text{barley}) = 1.2694x + 6.5616 \ (R^2 = 0.94)
\]

**Fig. 8.** Main effect of the (a) sowing depths and (b) alternating temperature regimes on the \( H_{50} \) parameter (number of days to reach 50% of the final plant height), as estimated with the use of the logistic function (Eqn 2): \( H_t = \frac{H_{\text{max}}}{1 + \left( \frac{T}{H_{50}} \right)^b} \). The vertical bars indicate the standard error of the estimated parameter. (●), wild barley; (○), wheat.

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(decreasing the $H_{50}$ value). During early growth, it is assumed that growth is primarily controlled by temperature (Kropff & Lotz 1992). Thus, not surprisingly, the relative growth rates that led to an increase in the shoot dry weight and green area increased with the temperature in winter wheat and three fall-germinating weeds (Storkey & Cussans 2000). Increasing the temperature from 15/10°C to 25/20°C reduced the $H_{50}$ values by 5 days, with no differences between wheat and wild barley in this respect. However, at 20/15°C, wheat needed two fewer days to reach its $H_{50}$ (Fig. 8b).

### Relative seedling emergence and height gain

To better compare the seedling emergence pattern and early growth of wild barley with those of wheat, all the wild barley parameters ($E_{\text{max}}$, $E_{50}$, $H_{\text{max}}$, and $H_{50}$) were expressed relative to the wheat coefficients. For example, a relative $E_{50}$ is the time taken from sowing to 50% emergence for wild barley divided by the time taken by wheat; values greater than unity (1.0) indicate that the weed emerged after the crop. In the case of the $E_{\text{max}}$ values, values $<1.0$ indicate that the maximum percentage emergence for wild barley is less than that of wheat. The same interpretation could be made for the relative $H_{50}$ and $H_{\text{max}}$ parameters.

When surface-planted, wheat emerged further ahead of wild barley at all temperature regimes (Fig. 9a). At 20/15°C, the emergence of wild barley on the surface was 73% slower than that of the wheat crop. The superiority of wheat over wild barley, in terms of the $E_{50}$, diminished as the sowing depth increased. Although, in most cases, there was a delay in the emergence of wild barley (relative to wheat), the relative $H_{50}$ values were affected rarely by the treatments (Fig. 9a). For a given temperature regime, the relative $H_{50}$ remained close to unity (1.0) at all sowing depths. However, exceptionally at 20/15°C for the sowing depth of 4 cm or at 25/20°C for the surface sowing, wild barley elapsed a 28% and 19% longer time to reach the 50% final height, respectively (Fig. 9a). This finding suggests that wild barley is able to make up for the delayed emergence by accelerating its growth rate, that is, rapid height gain. For example, at 20/15°C and surface planting, even the 73% delay in wild barley emergence (relative $E_{50} = 1.73$) only resulted in an 11% increase in the length of time to reach the 50% final height (relative $H_{50} = 1.11$) (Fig. 9a).

Increasing the sowing depth led to the emergence of a smaller number of wild barley seedlings, which was conceived by the lower relative $E_{\text{max}}$ values (Fig. 9b). The reduction in the relative $E_{\text{max}}$ values was more visible at 25/20°C, with the least value of 0.3 obtained from the sowing depth of 2 cm. The only exception occurred at 15/10°C for the burial depth of 2 cm, wherein the percentage emergence of wild barley was equal to that of the wheat crop (relative $H_{\text{max}} = 0.96$) (Fig. 9b).

At 15/10°C, for all the sowing depths, the relative $H_{\text{max}}$ values were always less than unity (1.0); in particular, at the depth of 6 cm in which wild barley was 33% (relative $H_{\text{max}} = 0.67$) shorter in height than wheat grown under the same planting condition (Fig. 9b). On the contrary, at 20/15°C, wild barley sown at different depths had the same height as wheat (the relative $H_{\text{max}}$ was close to 1.0). However, at 25/20°C, an increased sowing depth caused drastic reductions in the relative $H_{\text{max}}$ values, whereby wild barley plants sown 4 cm deep only gained as much as 37% of the height of wheat (Fig. 9b). Overall, the trend observed with the relative $H_{\text{max}}$ response to the treatments concurred with those of the relative $E_{\text{max}}$ changes, though the magnitude of the reductions was greater for the $E_{\text{max}}$ values. Therefore, it is deducible that, under conditions in which a fewer number of wild barley seedlings emerge (i.e. the relative $E_{\text{max}}$ value is reduced), these seedlings will have shorter heights (i.e. the relative $H_{\text{max}}$ value is reduced). In other words, the more unfavorable a condition for proper seedling emergence, the less suitable that is for the early growth of such plants and vice versa.

Assuming that the $E_{50}$ and $H_{50}$ share the same relative importance in the competitiveness of wheat and wild barley, one can suggest that wheat would acquire the greatest superiority over wild barley if sown shallowly at a temperature regime of 20/15°C, followed by 25/20°C (Fig. 9a). For the former planting condition, the summation of a 73% delay in emergence and 11% height gain produced a total growth retardation of 84% in wild barley (relative to wheat). For the latter condition, wild barley lagged by 72% (Fig. 9a). If again, we assume that the $E_{\text{max}}$ and $H_{\text{max}}$ contributions to the competition bear the same degree of importance, then the maximum superiority of wheat would be predicted to occur at 25/20°C and the sowing depth of 4 cm. Under this planting condition, the wild barley $H_{\text{max}}$ and $E_{\text{max}}$ values were reduced by 54% and 63% (summation: 117%), respectively (Fig. 9b). Presumably, wheat will compete with a fewer number of less vigorous (shorter in height) wild barley plants.

The findings of this experiment contribute to improving integrated wild barley management in wheat crops by providing information about the planting conditions...
under which wheat would take advantage of early establishment over wild barley or, in other words, wild barley is retarded in favor of wheat. For example, one may prefer to plant wheat sooner in early fall, which exposes the emergence and early growth stages to warm weather. A suite of agronomical actions then would be practised to plant the wheat seeds as deep as 4 cm (e.g. by exact drilling), while maintaining the seeds of wild barley as shallowly as possible (e.g. by implementing an untilled system). Under such planting situations, one can predict the delayed emergence (greater E$_{50}$ values) of fewer (lower E$_{max}$ values), slow-growing (greater H$_{50}$ and lower H$_{max}$ values) wild barley seedlings. However, we caution that such habitat-modification effects postulated under a controlled environmental condition could not be necessarily extended to field conditions, thus demanding further experiments to be conducted under field conditions.

Fig. 9. Wild barley parameter estimates of (a) E$_{50}$ (●) and H$_{50}$ (○) and (b) E$_{max}$ (●) and H$_{max}$ (○), expressed relative to the wheat parameters at different temperature regimes and sowing depths. The relative E$_{50}$ is the elapsed time to 50% emergence for wild barley divided by the time taken by wheat; values greater than unity (1.0) indicate that the weed needs a longer time to reach 50% of the maximum emergence. The relative E$_{max}$ is the maximum percentage emergence for wild barley divided by that of wheat. The E$_{max}$ values <1.0 indicate that the maximum emergence for wild barley is less than that of wheat. The relative H$_{50}$ and H$_{max}$ were calculated in the same way as above, having similar interpretations. Note that no seedling emerged during the 19 days of enumeration at 25/20°C and a sowing depth of 6 cm (shown by the dotted line).
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