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Effects of environmental factors on *Cucumis melo* L. subsp. *agrestis* var. *agrestis* (Naudin) Pangalo seed germination and seedling emergence

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ABSTRACT

Cucumis melo L. subsp. *agrestis* var. *agrestis* (Naudin) Pangalo (wild melon) is an invasive plant in many parts of Asia and North America. The reproduction of this species is by seeds, thus laboratory experiments were conducted in order to determine the cardinal temperatures and the effects of fluctuating temperature, heat, flooding stress, pH, seed longevity, and depth of burial on wild melon seed germination and seedling emergence. Of the three models tested, the intersected lines model best estimated the cardinal temperatures. The base, optimum, and maximum temperatures for wild melon seed germination were estimated as 20, 35, and 45 °C, respectively. The highest germination rates of wild melon were obtained at 30/20 °C and 35/25 °C (day/night). Only long exposure periods (up to 10 days) at 90 °C or greater than 5 min at 120 °C were efficient at reducing the germination of wild melon seeds. Flooding had limited impact on reducing wild melon seed germination until the third month after the treatment. The seeds of this weed germinated across a wide range of pH values, but germination rates were higher under acidic (pH 5) rather than basic (pH 8 and 9) conditions. Seed germination of wild melon, declined to 50% by the 23rd month after burial in the soil at 15 cm depth. Emergence of wild melon seedlings was higher at shallower burial depths than at deeper ones. These results suggest that the successful invasion of wild melon in an area can be explained, in part, by its tolerance to a wide range of environmental conditions. The combination of seed longevity, lack of seed dormancy and rapid seed germination under favourable climatic conditions may explain its rapid establishment as a weed in summer crops. Among the management strategies that can be used to limit the infestation of wild melon in the fields, burying seed deeply during soil preparation seems to be the most promising.

1. Introduction

Cucumis melo L. subsp. *agrestis* var. *agrestis* (Naudin) Pangalo (Smell melon or wild melon) is native to Eurasia and is an invasive species in many parts of the world. It is considered one of the major weeds of the Cucurbitaceae family, and it infests crops such as cotton (Prostko and Chandler, 1998; Tingle et al., 2003), peanuts (Grichar, 2007a), and soybean (Grichar, 2007b; Sohrabi et al., 2013). *C. melo* is an annual trailing or climbing vine, with flowers of both sexes on the same plant and reproduction only through seeds (Heywood, 1993). The main characteristics that differentiate the weed species from the cultivated *C. melo* are the size of the plant and the fruit; the plants and fruits of the cultivated species are larger than those of the weed. The fruits of this weed are berries, spherical to ovoid in shape, with dimensions ranging from 1.9 to 2.5 cm in diameter and 2–4.5 cm in length and they contain approximately 180 seeds (Kouonon et al., 2009; Sohrabi et al., 2014).

To prevent economic and ecological diversity losses, it is necessary to prevent additional introductions and invasions of plant species that have the potential to become serious pests of agriculture, forest, urban, and native areas. Understanding the basic biology and ecology of weeds is important to determine pathways of entry, spread, establishment, and persistence. The most important characteristics for weeds to thrive in new habitats are dependent on reproduction, dispersion, phenology, physiology, protection, habitat requirements, tolerance to environmental stress, and interspecific interactions (Bryson and Carter, 2004). Plants must also be able to survive during periods of adverse environmental conditions including heat, cold, drought, flooding, or inadequate aeration.

Germination is one of the most critical stages in weed establishment. Successful establishment of weeds depends heavily on their germination ability. Germination results from complex interactions among numerous internal (seed characteristics i.e. seed vigour, longevity...) and external controls (environmental conditions, i.e., moisture and temperature). Several environmental factors affect seed germination

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(Chauhan et al., 2006; Mennan and Ngouajio, 2006). Seeds of camel melon (*Citrullus lanatus* (Thunb.)), colocynth (*Citrullus colocynthis* (L.) Schrad.), and prickly paddy melon (*Cucumis myriocarpus* L.) are invasive weeds in Australia, which germinated at 28 °C (Shaik et al., 2012). There is little knowledge regarding the requirements for *C. melo* germination and emergence. This weed can germinate under adverse environmental conditions, such as salinity (NaCl) and drought stress (Tingle and Chandler, 2003; Sohrabi et al., 2013). *C. melo* can tolerate up to −8 MPa (about 10.168 g. $L^{-1} \approx 13$ ds m^{-1}) of salinity and −6 MPa of PEG (polyethylene glycol) during the germination and the early seedling stages (Sohrabi et al., 2013).

A better understanding of germination and emergence of *C. melo* seeds in relation to environmental variables may help to predict its potential spread into new areas and would be useful in developing effective control measures. This information may help explain why this weed has successfully invaded production areas in north Iran and other parts of the world. The objectives of this study of *C. melo* were (1) to evaluate its germination in response to temperature, heat and flooding stress, and solution pH; (2) to determine seed persistence in the soil; and (3) to evaluate the effect of burial depth on seedling emergence.

2. Materials and methods

Seeds of *C. melo* L. subsp. *agrestis* var. *agrestis* (Naudin) Pangalo were collected from soybean fields located in the Golestan province, in northern Iran, in August 2011. After harvest, the seeds were bulked, cleaned manually, placed in a paper bag, and stored at room temperature. Seed dormancy was not detected either prior to or after storage. Experiments were conducted at the Seed Technology Laboratory at Gorgan University of Agricultural Sciences and Natural Resources, Iran, during 2011–2012.

2.1. Germination protocol

Unless otherwise stated, all experiments were conducted using the following protocol. Germination was evaluated by evenly distributing 25 seeds (in each replicate) on a moist paper towel soaked in 10 mL of distilled water. Subsequently distilled water (or test solution) was added on a regular basis to maintain appropriate water availability. The experiments were performed in a completely randomised design, with four replicates per treatment. Each experiment was repeated twice. A seed was considered to have germinated when a visible radicle could be discerned, and at that time, it was removed from the paper towels. Seed germination was up to 99% according to primary germination tests indicting high seed viability. Consequently, tetrazolium chloride tests were not necessary (ISTA, 2009). The time of seed germination and number of seedlings were noted as they germinated. Then, the germination rate was calculated as.

$$S = \frac{E_1}{N_1} + \frac{E_2}{N_2} + \ldots + \frac{E_n}{N_n} \tag{1}$$

where S is the germination rate, E is the number of germinated seeds per day, N is the number of days, and n is the number of days to final observation (Steinmaus et al., 2000).

2.2. Temperature

2.2.1. Cardinal temperatures

To determine the cardinal temperatures for germination of *C. melo*, seeds were incubated at 20, 25, 27, 30, 35, 37, 40, 43 and 45 °C for 2 weeks at constant temperatures in the dark. The cardinal temperatures were estimated by regression analysis on germination rate (GR) and temperature (T) using an intersected lines model (ISL) (Eq. (2)), five-parameter beta model (5-Pβ) (Eq. (3)), and quadratic polynomial model (QP) (Eq. (4)):

$$\begin{aligned} GR &= b*(T-T_b) \ \text{ if } \ T \le T_0 \\ GR &= c*(T_c-T) \ \text{ if } \ T \ge T_0 \end{aligned} \tag{2}$$

$$\begin{aligned} f &= \exp(\mu)(T-T_b)^{\alpha}(T_m-T)^{\beta} \\ T_o &= \frac{\alpha T_m + \beta T_b}{\alpha+\beta} \end{aligned} \tag{3}$$

$$\begin{aligned} f &= a + bT + cT^2 \\ T_o &= b + 2cT \end{aligned} \tag{4}$$

where T_b, T_o, and T_c are considered the base, optimum, and maximum temperatures, respectively, and a, b, c, α, and β are the regression coefficients. The root mean square error (RMSE, Eq. (5)) was used to measure the difference between the measured and calculated values, where N is the number of data points, $(\sum_{i=1}^{n}(Yi-\hat{Y}))$ is the sum of squares (SS) of regression, Y_i is the observed value, and $\hat{Y}$ is the corresponding estimated value (Kobayashi and Salam, 2000; Derakhshan et al., 2014).

$$\mathrm{RMSE} = \sqrt{\left(\frac{1}{N}\right)\sum_{i=1}^{n}\left(Yi-\hat{Y}\right)^2} \tag{5}$$

2.2.2. Fluctuating temperatures

To determine the effect of fluctuating temperature on germination, seeds of *C. melo* were incubated at temperatures of 25/15, 30/20, 35/25, and 45/35 °C, with 12 h light and 12 h darkness, daily. These temperature regimes tested correspond approximately to the range of day and night temperatures that occur during the growing season of this weed species in the main infested regions of the world.

2.3. Seed longevity

During autumn 2011 (the natural time of seed dispersal), *C. melo* seeds were buried approximately 15 cm under the soil surface (crop planting depth) at the Research Farm of Gorgan University of Agricultural Sciences and Natural Resources, Iran, (36° 85′N, 54° 27′E) with annual rainfall 607 mm, using sachets constructed from 100-μm stainless steel mesh. The soil type was loamy, with 18% sand, 46% silt, 36% clay, and 1% organic matter and a soil-water pH of 7.6. Every 6 months, seed viability in retrieved sachets was assessed using a germination test.

A logistic equation was fitted to the seed germination data (Kebreab and Murdoch, 1999). The viable proportion of the seeds, P, was modelled as

$$P = \frac{100}{1 + \exp(k(t-m))} \tag{6}$$

where t is the burial time in months, m is the time until viability has been reduced to 50%, and k is a curve shape parameter. The initial asymptote was set at 100, assuming that all seeds were initially viable.

2.4. Solution pH

Buffered pH solutions were prepared according to the method described by Gortner (1949) using potassium hydrogen phthalate in combination with 0.1 M HCl to obtain solution pH levels of 4, 5, and 6. A 25 mM sodium tetraborate decahydrate solution was used in combination with 0.1 M NaOH to prepare solutions with pH levels of 7, 8, or 9 (Gortner, 1949). Seeds of *C. melo* were placed on moist paper towels containing 10 mL of the appropriate pH solution. The moist paper towels were rolled and placed in an incubator at 35 °C in the dark.

2.5. Heating stress

The effect of heat stress on *C. melo* seed germination was simulated in the laboratory at different temperatures for varying durations. Seeds of *C. melo* were exposed to heated air in an oven using a completely randomised design with a factorial arrangement of the treatments. The effect of burning was simulated by exposing the seeds to three temperatures (100, 120, and 140 °C) over three exposure periods (5, 10, and 15 min). To simulate the conditions of compost or solarisation, the treatments included three temperatures (70, 80, and 90 °C) and six exposure times (1, 3, 5, 7, 10, and 15 days). Seed mortality data were analysed using nonlinear regression (Myers, 1986), as follows:

$$m = c/\left\{1 + e^{[-b_1(d-b_0)]}\right\} \quad (7)$$

where m is mortality, expressed as the percentage of the control, d is the duration of exposure to the temperature, in hours or days, c is a constant value, b_0 is the estimated 50th percentile for mortality, and b_1 is the mortality rate (which was calculated in an analogous manner to the germination rate).

2.6. Flooding stress

To investigate the effects of flooding conditions on the seed germination of *C. melo*, the seeds were placed in fresh distilled water at room temperature for up to 300 days. Water in the container was replaced weekly. Then, every month, one hundred seeds were removed from the water and germination tested in the lab. For each replicate, the seeds were incubated on moist paper towels with distilled water and kept in the dark at 35 °C.

2.7. Seed burial depth

Plastic pots that were 15 cm in diameter and 1 L in capacity were filled with soil and used to evaluate the effect of the burial depth on *C. melo* seed germination. The treatments consisted of seeds buried at 0.25, 1.5, 2.5, 5, 7, 10, 15, or 20 cm depths. Each treatment was replicated four times, and each replicate had ten *C. melo* seeds. The pots were placed randomly inside a growth chamber under fluctuating day/night temperatures (35/25 °C) and light/dark (12/12 h) periods. Pots were watered daily to maintain the soil at field capacity. Pots were checked daily for seedlings, which were considered to have emerged when cotyledons were visible at the soil surface. Once a seedling reached this stage, it was removed from the pot.

Each depth, date of sprouting and number of seedlings were noted as they emerged. An exponential decay model (Eq. (8)) was used to determine the relationship between the burial depths of seeds and emergence:

$$G = ae^{-bD} \quad (8)$$

where G is the proportion of seedling emergence, a is the maximum number of seedlings that could potentially emerge, D is the burial depth, and b is a curve shape parameter (Hugo et al., 2014).

2.8. Statistical analysis

The data collected from the experiments were tested using an analysis of variance (ANOVA), and because there was no significant experiment-by-treatment interaction, the data were pooled for further analyses. Regression analyses were performed using Sigma Plot 8.0 to determine the effects of heating stress, seed burial on seed longevity, and of burial depth on seedling emergence. A one-way ANOVA analysis was performed using SAS 9.1 (SAS institute, Cary, NC, USA) to assess the effects of pH and temperature fluctuation on germination. Significant differences among treatments were identified using an LSD test ($P < 0.05$). The data met all normality conditions, therefore, data transformation was not required.

3. Results

3.1. Temperatures

3.1.1. Cardinal temperatures

The ISL model structure was found to be the best model to predict germination rate ($R^2 = 0.97$, RMSE = 1.11) (Table 1). Based on this model output, the base, optimum, and maximum (ceiling) temperatures for *C. melo* germination were estimated as 20, 35, and 45 °C, respectively. Germination declined rapidly with increasing or decreasing temperatures above or below the optimum of 35 °C (Fig. 1). At 35 °C, 100% of seeds germinated.

Of the three models tested, RMSE values indicate that the ISL model predicts the cardinal temperatures of *C. melo* better than the other two models tested because of the relative model fit as a function of model type, seeds and temperature (Table 1).

3.1.2. Fluctuating temperatures

The greatest percent germination of *C. melo* was obtained at 30/20 and 35/25 °C (day/night), and the highest germination rate was obtained at 35/25 °C (day/night). Germination percent and rate were significantly lower at 25/15 and 45/35 than at 30/20 and 35/25 °C (Fig. 2a and b); maximum *C. melo* seed germination (100%) was observed at both 30/20 and 35/25 °C fluctuating temperature regime.

3.2. Seed longevity

At the time of seed burial at 15 cm (crop planting depth), *C. melo* germination was 100%, indicating high seed viability. Germination tests after 6 and 12 months of burial at 15 cm depth indicated that there was no loss in seed viability during that time. After 23 months of seed burial, the logistic model predicted that the rate of decline of *C. melo* seed germination was approximately 0.34 (seed/day) and resulted in a 50% decline in subsequent germination. Seed viability was significantly lower after 18 months of seed burial at planting depth than when originally buried (Fig. 3).

3.3. Response to solution pH

C. melo seeds germinated across a broad range of pH (4–9) values. No significant difference was detected across the range of pH from 4 to 8, but germination percentage decreased significantly at pH 9 (Fig. 4a). The germination rate of *C. melo* seeds was highest (9 seeds/day) at pH 5 to 7; however, it was significantly lower (less than 5 seeds/day) at pH 8 and 9. In the acid-treated seeds, initial germination occurred significantly earlier than seeds in basic solutions. Percent and rate germination at pH 4 were about 80% and 8 seeds/day, respectively (Fig. 4a and b).

Table 1
Estimated parameters of three different models for estimating cardinal temperatures of *Cucumis melo*.

Models	T_b	T_o	T_c	R^2	P_{value}	RMSE
ISL	20.53 (0.49)	35.7 (1.3)	41.96 (0.28)	0.97	0.0001	1.11
5-Pβ	19.99 (2.12)	35.4 (1.4)	40.13 (0.64)	0.91	0.0001	1.97
QP	20.44 (3.18)	32.98 (1.2)	44.12 (0.02)	0.68	0.0001	3.73

ISL: intersected lines model; 5-Pβ: five-parameter beta model; QP: quadratic polynomial model.
Standard errors are presented in parentheses.

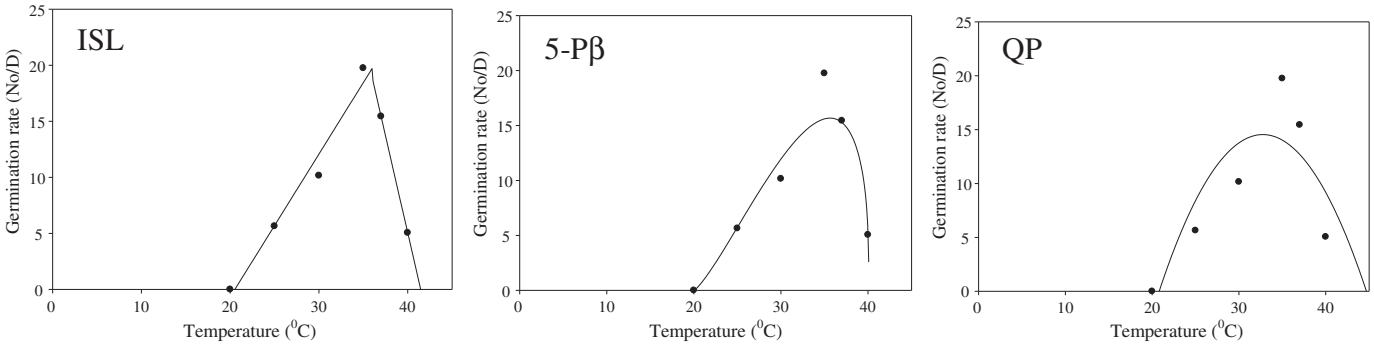

Fig. 1. Predicted germination rate at different constant temperatures using ISL, 5-Pβ, and QP models (equations on Table 1).

3.4. Heating stress

The time to total seed mortality varied considerably at each temperature studied (Table 2). Seeds were more susceptible to 90 °C heat treatment than 70 and 80 °C temperatures. The observed duration of the heat treatment required to kill 50% of the weed seeds (b_0) when the seeds were exposed to temperatures of 90 °C was 9.8 days. However, when the seeds were exposed to 120 °C, the b_0 was approximately 4.8 min (Table 2). The 100 °C treatment did not affect seed viability within the 16 min tested, but at 140 °C, the seeds were all dead within 10 min (Fig. 5a and b).

3.5. Flooding stress

C. melo seed germination was not inhibited by constant saturated conditions or by treatments flooded up to 90 days. The highest germination percentage and germination rate were 100% and 19.5 (number of germinated seeds/day), respectively. The required flooding times for 50% reduction of seed germination rate and percentage were 138 and 147 days, respectively (Fig. 6a and b). After 120 days of flooding, the germination percent was significantly less than after the first 100 days of flooding. The germination rate of *C. melo* was significantly reduced after 120 days of flooding.

3.6. Seed burial depth

The emergence of *C. melo* seedlings decreased rapidly with increasing planting depth. Emergence was greatest (64%) for seeds placed at the shallowest depth (0.25 cm), and no seedlings emerged from seeds placed at soil depths greater than 10 cm (Fig. 7a and b). The highest emergence rates were observed from the superficial (0.25 cm) and 1.5 cm seed depths (Fig. 7). Percent emergence of seeds exceeded 30% at depths of up to, and including, 5 cm.

4. Discussion

The cardinal temperatures detected in this work indicate that *C. melo* L. subsp. *agrestis* var. *agrestis* (Naudin) Pangalo seeds need warm environmental conditions for germination (Fig. 1). Other researchers have also reported that the optimum germination temperature for the closely related variety *C. melo* L. subsp. *agrestis* (Naudin) Pangalo var. *dudaim* (L.) Naudin was between 30 and 35 °C, very similar to the one presented in this study (Tingle and Chandler, 2003). Likewise, Tanveer et al. (2012) reported that time to 50% seed germination of *C. melo* subsp. *agrestis* var. *agrestis* increased with rising temperature, and the maximum and minimum temperatures for seed germination were found to be 45 °C and 25 °C, respectively. The difference between the estimated minimum temperature in the current study and the result reported by Tanveer et al. (2012) could be due to different ecotypes studied. Seeds of the Cucurbitaceae family require warm temperatures for successful germination but differ in their ability to germinate at low temperatures (Edelstein and Kigel, 1990; Edelstein et al., 2001).

Among the intersected lines (ISL), five-parameter beta (5-Pβ), and quadratic polynomial (QP) models, the ISL model was the best model for estimating cardinal temperatures of *C. melo*. The type of model that most accurately estimates the optimal temperature range depends on the plant species (Hardegree, 2006). The nonlinear and segmented models were, respectively, found to be the best models to estimate the

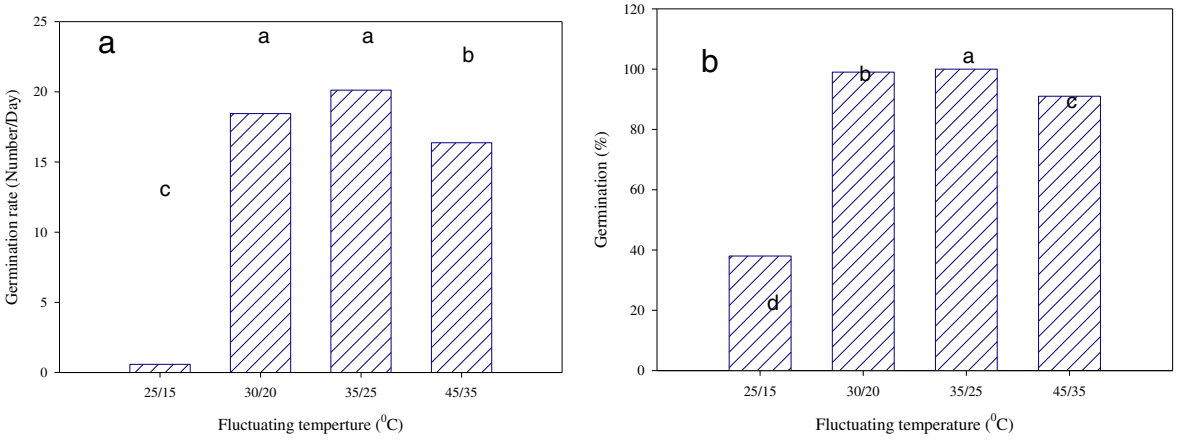

Fig. 2. Effect of fluctuating temperatures on percent and rate of *C. melo* seed germination.

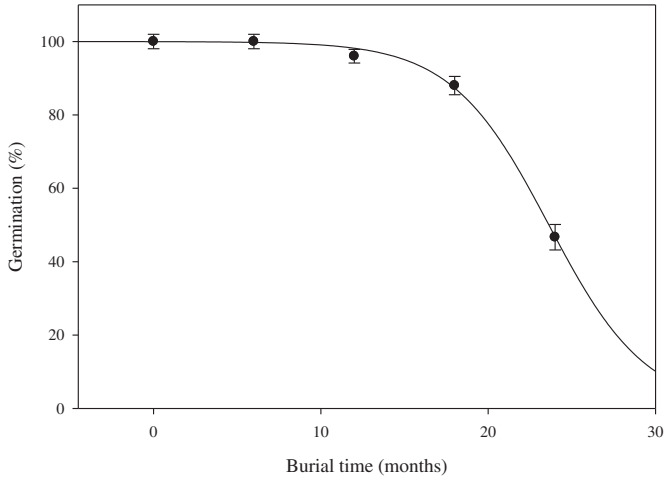

Fig. 3. Effect of burial time on *C. melo* seed germination when the seeds were placed at a depth of 15 cm.

Table 2
Nonlinear models describing the relationship of duration of heat treatment to mortality using the equation $m = c/\{1 + e^{[-b1(d-b0)]}\}$, where m is mortality, c is a constant value, d is duration of exposure at a specific temperature, b_0 is the estimated 50th percentile for mortality, and b_1 is the mortality rate.

Temperature	b_0	b_1	c	R^2	P_{value}
Days					
70 °C	4.24 (0.79)	−0.41 (0.11)	10	0.95	0.0021
80 °C	5.2 (0.56)	−0.41 (0.07)	20	0.98	0.0004
90 °C	9.8 (0.72)	−0.45 (0.09)	110	0.98	0.0002
Minutes					
100 °C	38 (718)	−0.21 (0.3)	188	0.88	0.37
120 °C	4.8 (0.004)	−4.4 (0.19)	100	1.0	0.0001
140 °C	0	0	0	0	0

Standard errors are presented in parentheses.

cardinal temperatures for five weedy *Oryza sativa* L. populations and for *Papaver somniferum* L. (Adam et al., 2010; Kamkar et al., 2012). The knowledge of the cardinal temperatures for *C. melo* seed germination can be helpful for phenological studies and also for the decision-making process concerning the strategies and periods for management of this weed species. Scientists have developed thermal time models to predict emergence of weed species based on daily accumulation of heat units or growing degree days (GDD) above a base temperature (Grundy, 2003). Thermal time has been used for predicting the emergence of 23 summer annual weed species (Werle et al., 2014).

The highest germination of *C. melo* occurred at 30/20 and 35/25 °C (day/night) (Fig. 2a and b), which is similar to that reported for other summer broadleaf weed species such as *Bidens pilosa* L. (Reddy and Singh, 1992), *Brunnichia ovata* (Walter) Shinners (Shaw et al., 1991), and *Murdannia nudiflora* L. (Wilson et al., 2006). The optimum temperature reported for these weeds ranged from 25 to 35 °C. Onset, rate, and total germination (87%) of *Brachiaria platyphylla* (Griseb.) were greatest in an alternating 30/20 °C temperature regime (Burke et al., 2003). The optimum germination of *Caperonia palustris* L. occurred with a fluctuating 40/30 °C temperature regime (Koger et al., 2004). The optimum day/night temperature range for the germination of *Ipomoea purpurea* (L.) Roth, was 20/12.5 to 35/25 °C (Singh et al., 2012).

The germination of *C. melo* seeds started to decline steadily after 12 months in the soil when buried at 15 cm depth (Fig. 3), and after about 23 months, seed viability declined to 50%. According to this result, it seems that seeds of wild melon cannot persist for a long time in the seed bank. Hence fields are most likely to be re-infested by seeds that are less than 2 years old. It is possible that preventing seed production for at least 3 years will effectively reduce the seed bank of this species. It is worth mentioning that seed longevity may differ with soil conditions (such as soil temperature, moisture, pH, microbial population etc.), depths of burial and weed species. Decline in seed viability of *Phelipanche muteli* F. W. Schultz was dependent on seed burial depth and environmental conditions (Prider et al., 2012). The seed longevity of some noxious weeds such as *Chondrilla juncea* L. and *Cardaria* spp., in Nevada, was less than 3 years (Schultz, 2013).

The ability of *C. melo* to germinate and grow over a wide pH range (Fig. 4a and b) indicates that soil pH would not be a major limiting factor for the occurrence of this weed in most agricultural soils and may explain the ability of this species to invade new environments. Likewise, the seeds of two weed species *Brunnichia ovata* (Walter) Shinners (Shaw et al., 1991) and *Cassia occidentalis* L. (Norsworthy and Oliveira, 2005), have been reported to germinate in soils with a wide range of pH values.

The fact that the sensitivity of *C. melo* seeds to heat stress depends on the temperature and duration of exposure to high temperature (Fig. 5a and b) suggests that solarisation, soil steaming, or composting weed seeds can be investigated as viable tactics to reduce the soil seed bank of this species. Results from the literature indicate solarisation, at 99 °C for 20 s, could be an alternative to reduce the soil seed bank of *Digitaria sanguinalis* (L.) Scop., *Diodia virginiana* L. and *Kyllinga squamata* Thonn. ex Vahl. (Hoyle and Mcelroy, 2012). It has been reported that the temperature of fire, during burning of straw, reaches up to 200 °C at the

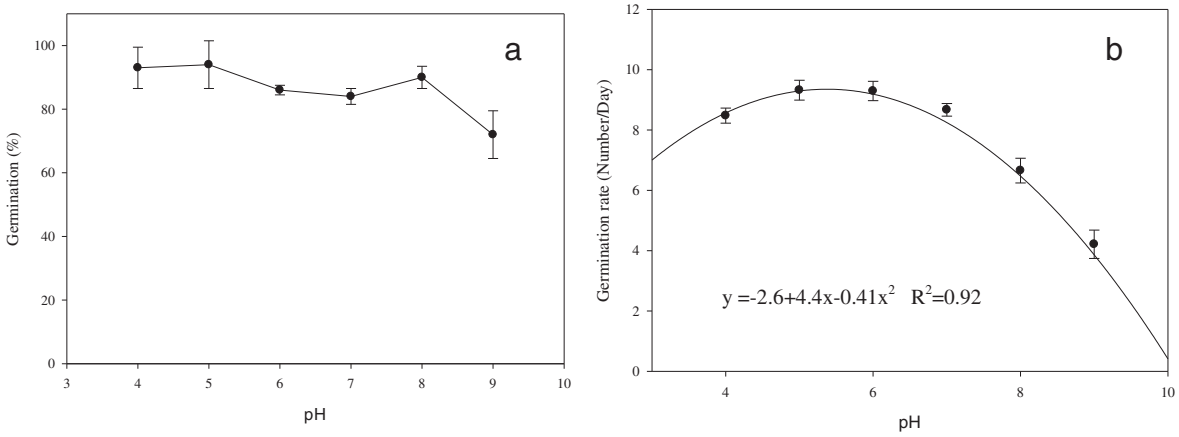

Fig. 4. Effect of pH on percent and rate of *C. melo* seed germination.

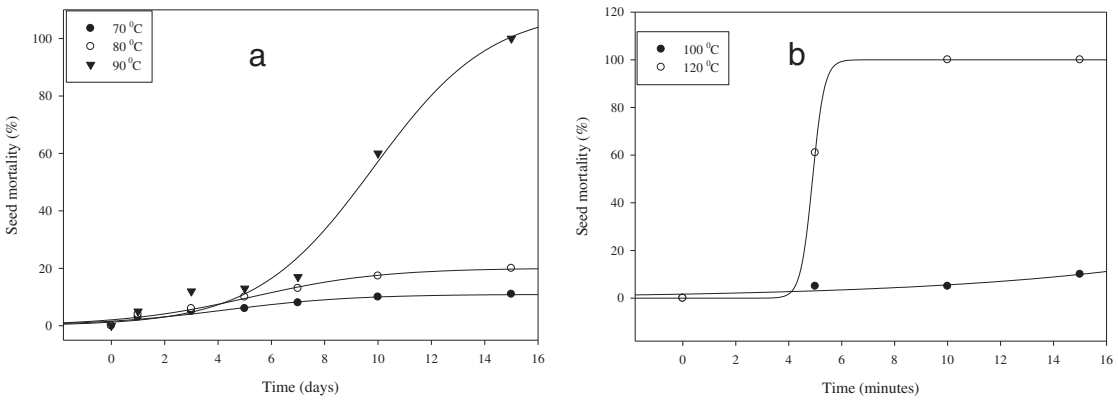

Fig. 5. Effect of heating temperature on seed mortality of *C. melo*. (equations on Table 2).

soil surface and up to 60 °C at a soil depth of 5 cm (Coleman et al., 1993). Results of some studies showed that heating at 120 °C for 2 min reduces seed germination of *Sinapis arvensis*, *Sonchus arvensis*, *Daucus carota* (Coleman et al., 1993), and *Gompholobium grandiflorum* (Ooi et al., 2014). Results of our study suggest that burning straw in the field may cause *C. melo* seed death at the soil surface and hence reduce the number of seeds in the seed bank. The impact of fire on the *C. melo* seed bank, however, needs to be further investigated.

Flooding does not appear to be a practical option for *C. melo* control in rotation with rice production because its seeds can germinate even after 3 months of flooding (Fig. 6a and b). Likewise, the germination rates of other weed species, such as *Diodia virginiana* (L.) and *Morrenia odorata* (Hook. & Arn.), were not affected by flooding (Baird and Dickens, 1991). By contrast, flooding can be used to reduce the seed germination of other weed species, such as *Caperonia palustris* (L.) (Koger et al., 2004) and *Ipomoea purpurea* (L.) Roth, (Singh et al., 2012). In certain plant species, the tolerance to flooding stress was positively correlated with the seed mass and with the seedling root growth parameters (Armstrong and Drew, 2002). The sensitivity of melon seed germination to excess water was related to tested structure and temperature (Edelstein et al., 1995).

The fact that the emergence of *C. melo* seedlings was reduced by deeper seed burial (Fig. 7a and b) suggests that burying seeds through tillage may reduce the impact of this species on crop yield. However, the long-term efficacy of tillage to control *C. melo* would be dependent on seed longevity (Oliveira and Norsworthy, 2006; Vidal et al., 2007). Similar to the results presented here, the seedling emergence in other *C. melo* varieties was dependent on the depth of seed burial. For instance, the highest seedling emergence in *C. melo* subsp. *Agrestis* var. *dudaim* occurred from depths of 1 to 6 cm (Tingle and Chandler, 2003), whereas in *C. melo* subsp. *agrestis* var. *agrestis* the highest seedling emergence occurred at 0 to 1 cm (Tanveer et al., 2012), and in both cases, the emergence decreased strongly with increasing soil depth. Tillage operation can redistribute the seed in the soil profile and place it into an environment, which is more (or less) conducive to germination and emergence.

Overall, the potential of *C. melo* seed emergence at fluctuating temperatures and shallow burial depths may indicate adaptation of this species to disturbed bare ground where the greatest diurnal fluctuations would be expected. Shallow cultivation for weed control could potentially stimulate germination by placing *C. melo* seeds at the optimum depth for germination. The optimum germination temperature for *C. melo* (about 35 °C) coincides with those for many annual crops such as soybean, sunflower, cotton, etc. (Sohrabi et al., 2013).

C. melo seed germination is observed across a wide range of environmental conditions. The results from this work suggest that the successful invasion of this species in an area can be explained, in part, by the ability of *C. melo* seeds to germinate and to emerge under different environmental conditions. Two characteristics, lack of seed dormancy and high seed germination percentage under favourable climatic conditions, may explain the rapid weed establishment in summer crops. Also, there is flexibility for seed germination late in the growing season and under adverse environmental conditions, which may aid *C. melo* in evading control tactics that are usually employed during crop establishment and early season weed management. Among the management strategies that could be used to limit the infestation of *C. melo* in the crops, deep seed burial during soil preparation seems to be the most promising.

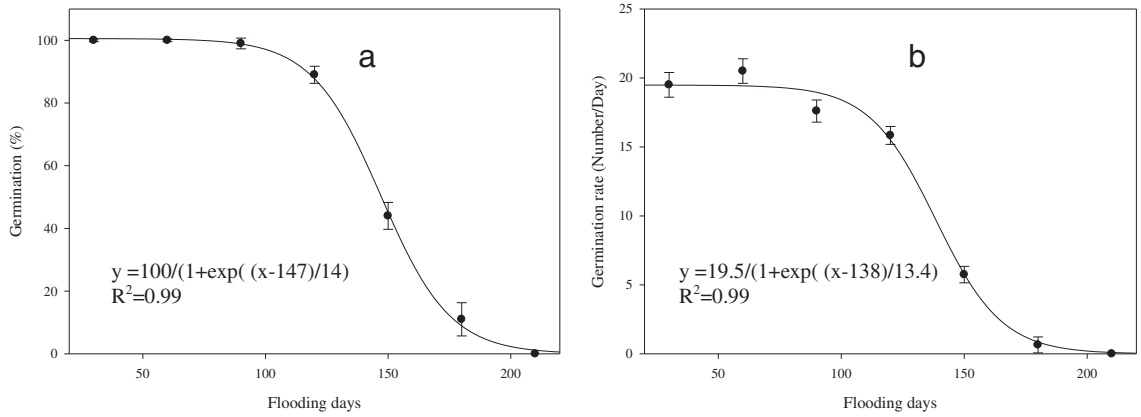

Fig. 6. Effect of flooding on percent and rate of *C. melo* seed germination.

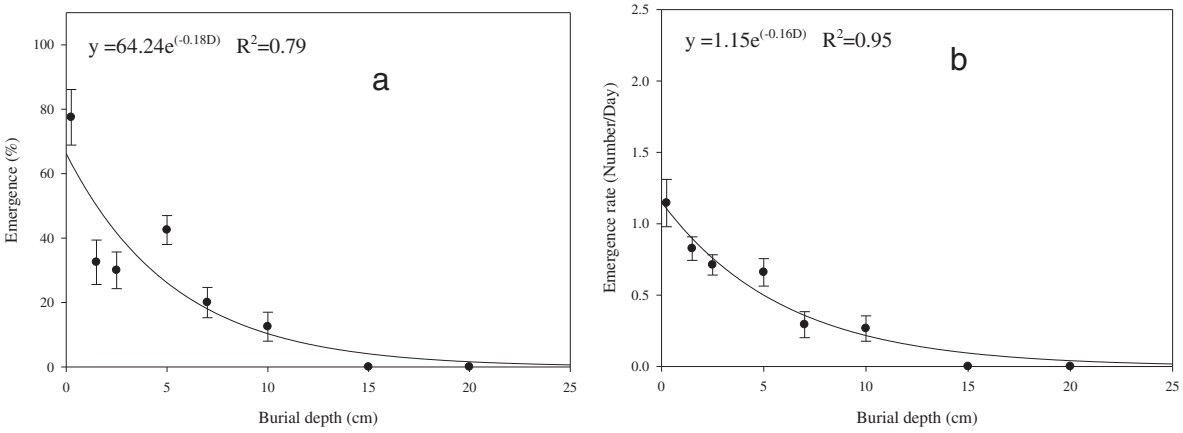

Fig. 7. Effect of planting depths on percent and rate of *C. melo* seedling emergence.

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