The reproductive capacity of parthenium weed (*Parthenium hysterophorus* L.) under different climatic conditions

Thi L.T. Nguyen, Sheldon C. Navie and Steve W. Adkins
University of Queensland, Tropical and Subtropical Weeds Research Unit, School of Land, Crop and Food Sciences, St Lucia, Qld 4072, Australia
Corresponding author: tnguyen@uq.edu.au

Summary The seed production of parthenium weed (*Parthenium hysterophorus* L.) was studied in pot trials under two temperature (28–35°C – Warm or 18–25°C – Cool) and two soil moisture (field capacity – Wet; or half of field capacity – Dry) regimes. The highest amount of seed (26,628) was produced under the Warm/Wet conditions while the Cool/Wet conditions produced the lowest amount of seed (15,510) per plant. However, a proportion of this seed was unfilled (as determined by X-ray analysis), with the greatest number of unfilled seed found under the two Cool regimes (*c.* 60%). Small amounts of dormant seed were also produced, with the highest amount found under the two Warm regimes (*c.* 9% or 1500 seed per plant). The germination percentage of all filled and non-dormant seed was *c.* 98%, indicating a very high seed viability under all production regimes and highlighting the remarkable reproductive ability of this species. When using a laboratory-controlled ageing test to predict seed persistence in the field, it was discovered that the seed produced under the two Warm regimes was likely to survive in the soil seed bank longer (i.e. for 3 years) than that produced under the two Cool conditions (i.e. for 1–3 years).

Keywords Parthenium weed, reproduction, dormancy, seed longevity.

INTRODUCTION

Parthenium weed (*Parthenium hysterophorus* L.) belongs to the Asteraceae family, and is described as an aggressive herbaceous weed of tropical and subtropical environments. Parthenium weed is native to the tropical and subtropical Americas including regions in North, Central and South America, and the Caribbean. Parthenium weed has been introduced into Australia from North America on two separate occasions – the first was in the 1940s at Toogoolawah in south-eastern Queensland and the second was in 1958 in Clermont, central Queensland (Adkins and Navie 2006). In Australia, parthenium weed exists mainly in Queensland, and has been found in New South Wales, Victoria and the Northern Territory. In 2002, parthenium weed was made a Weed of National Significance in Australia.

Parthenium weed begins to flower 4 weeks after emergence and this can happen at any time of the year. The process of seed production occurs uninterruptedly until the plants senescence (Haseler 1976). Five cypselas (hereafter referred to as seeds) of the same size are produced in most flower-heads (Lewis *et al.* 1988). The production of seed per plant has been reported to be as high as 15,000 by a typical mature plant in the field in central Queensland (Haseler 1976) or 22,500 in India (Muniyappa and Krisnamurthy 1981). In another study, one parthenium weed plant in a pure stand in India was shown to produce 5952 inflorescences and therefore, about 30,000 seeds (Joshi 1991).

Inconclusive results have been published on the initial dormancy status of parthenium weed seeds. Almost 100% of the mature freshly shed seed germinated in a period of 21 days. This result led to the conclusion that the seed has no physical or physiological dormancy (Butler 1984, McFadyen 1994). However, sesquiterpene lactones and phenolic acids present in parthenium weed seeds can regulate germination by inducing a dormancy that can be removed by soaking seeds in a moist environment. The highest germination percentage of 94.4% was achieved when soil moisture was kept high (Picman and Picman 1984). Because seeds incubated soon after collection do not reach the same high level of germination (*c.* 70 to 85% of germination for 4 weeks) as those that have been leached with sodium hypochlorite, or those that were buried for several months in periodically damp soil (*c.* 95% germination after some days), Navie *et al.* (1998) concluded that there is some initial inhibition of germination (or dormancy) in freshly-shed seeds. In support of this view, Tamado *et al.* (2002) reported that freshly harvested seed had germination of only 5.3 ± 1.8% in the light (or 0% in darkness), but after 1 month of burial in soil, the germination percentage could be increased (*c.* 60%), both in the light and dark. In another study, Karlsson *et al*. (2008) stated that cold stratification reduced dormancy characteristics of parthenium weed seeds.

According to Williams and Groves (1980), Australian parthenium weed seeds can germinate in a wide range of temperatures, including those as low as 10°C or as high as 36°C. The viability of parthenium weed seeds was also found to be >90% in the temperature range 12–25°C (Navie *et al.* 1998).

Butler (1984) reported that the germination of parthenium weed seeds declined from 66% after 1 week of burial to 12% after burial for 2 years. It was also found that depth of burial, in the range of 2 to 20 cm, did not significantly affect parthenium weed seed longevity. However, Navie *et al.* (1998) stated that there was 74% seed viability after 2 years' burial and the predicted half-life of the parthenium weed seeds was about 6 years. According to Tamado *et al.* (2002), the viability of parthenium weed seeds was >50% after 26 months of burial in the soil and that the 'half life' of seeds in the soil was *c.* 3–4 years.

This present study aimed to investigate aspects of the seed biology of parthenium weed, including the reproductive capacity and quality (fill, dormancy and longevity of seeds) under different climatic conditions (temperature and soil moisture).

MATERIALS AND METHODS

Parthenium weed plants (seeds from the Clermont, central Queensland) were grown in pots containing a typical heavy clay soil and subjected to two temperatures (28–35°C, 18–25°C; night/day) and two soil moisture regimes (field capacity, 0.5 field capacity) in a series of environmentally controlled glasshouses for 7 months. Seeds from these plants were collected and dried (to 15% relative humidity and 15°C) then tested for fill (using an X-ray test), dormancy (using a germination test and viability test), and potential longevity in a soil seed bank (using an accelerated ageing test).

The X-ray test used an X ray machine (Faxitron model MX20) to provide information on the empty versus filled status of the seed produced. To do this seeds produced in the mid point of flowering were selected and studied.

To test germination, four replicates of 25 fresh seeds each were surface-sterilised in a sodium hypochlorite solution (NaOCl, 1% v/v) for 1 min. The seeds were then washed in distilled water and placed in 9 cm plastic Petri dishes lined with two 9 cm diameter Whatman No.1 filter papers and moistened with 7 mL of distilled water. The Petri dishes were sealed with laboratory film (Parafilm^{TM}) and then placed into a germination incubator, which was set to a 12 h photoperiod and a 25/20°C day/night thermoperiod. The seeds were kept under these conditions for 75 days, and germination was recorded daily.

Viability was measured using the tetrazolium method, a biochemical test using a 1% tetrazolium salt solution (2,3,5-triphenyl tetrazolium chloride). This can differentiate between live and dead tissues, especially those of the embryo, on the basis of their dehydrogenase enzyme activity. A red formazan compound will be produced in living cells, while dead cells will remain colourless. The viability of seeds that did not germinate in the germination test was based on their final embryo staining pattern after tetrazolium application.

The accelerated ageing test applies high temperature and relative humidity (RH) conditions to seeds and tests their resilience to ageing. Twelve replicates of 50 seeds were placed into individual open glass vials and then placed over a 47 ± 1.5% RH lithium chloride solution (370 g L^{-1} H_2O) within a sealed box at 20 ± 1°C for 14 days to pre-equilibrate the seed moisture content. Vials were then transferred to a second sealed box at 60 ± 1.5% RH lithium chloride solution (300 g L^{-1}) in an oven set at 45 ± 0.5°C for ageing. Vials were removed periodically throughout the aging process and tested for viability, as measured by their normal 42 day germination percentage and the tetrazolium test (Davies and Probert 2004).

All data were analysed by an analysis of variance test using General Linear Model procedure in Minitab – Version 15.

RESULTS

Seed production under two temperature regimes (28–35°C – Warm or 18–25°C – Cool) and two soil moisture levels (Field Capacity – Wet or half of field capacity – Dry) showed that plants under Warm, Dry conditions produced seeds the earliest (after 50 days), while plants under Cool, Wet conditions produced latest (after 75 days). In addition, the Warm/Wet conditions produced the highest number of seeds (26,628) while the Cool/Wet conditions produced the lowest number of seeds (15,510) per plant. Moreover, the plants grown under the Warm conditions produced more seeds (24,421) than those in the Cool conditions (18,512) ($P = 0.000$) while the plants grown under Dry or Wet conditions (21,866 and 21,068, respectively) did not show significant differences ($P = 0.923$) (Table 1).

However, for each condition a proportion of the seeds was empty (unfilled). The greatest number of unfilled seeds was produced under the two Cool conditions (>60%) but no significant difference existed between Dry and Wet conditions ($P = 0.505$). Dormant seeds were also produced, with the highest number being produced under the two Warm conditions (*c.* 9% or 1500 filled seeds per plant) compared with two Cool conditions (*c.* 2% or 150 seeds per plant) ($P = 0.011$). The immediate germination percentage of all filled and non dormant seeds from the Cool/Dry treatments was *c.* 98% indicating the very high viability of the seeds produced and the plant's remarkable ability to reproduce (Table 1).

Table 1. The mean number of filled, empty, dormant and dead seeds produced per plant from 10 replicate plants grown under four conditions of temperature and soil moisture.

Conditions	Filled seed	Empty seed	Dormant seed	Dead seed	Total seed
Warm Dry	11,736	10,479	1,091	188	22,215
Warm Wet	17,963	8,665	1,778	72	26,628
Cool Dry	8,069	13,448	105	65	21,517
Cool Wet	5,362	10,148	150	91	15,510

A recently developed laboratory-controlled ageing test, which is thought to be able to predict seed persistence in the field (Long *et al*. 2008) was applied to the viable seed produced. The data show that seeds produced under the two Warm conditions had a P_{50} value (the time for seed viability to decline by 50%) in the controlled ageing test of around 75 days (Figure 1). This means that seeds produced under Warm conditions are likely to have a longer persistence in the soil (>3 years) than those produced under the two Cool conditions (1–3 years; a P_{50} value of around 50 days). Moreover, the survival curves over time for the two Warm conditions indicates that this seed is likely to be able to persist in the soil more than that produced under the two Cool conditions (P = 0.000). The soil moisture level did not seem to affect seed life in the soil (P = 0.351).

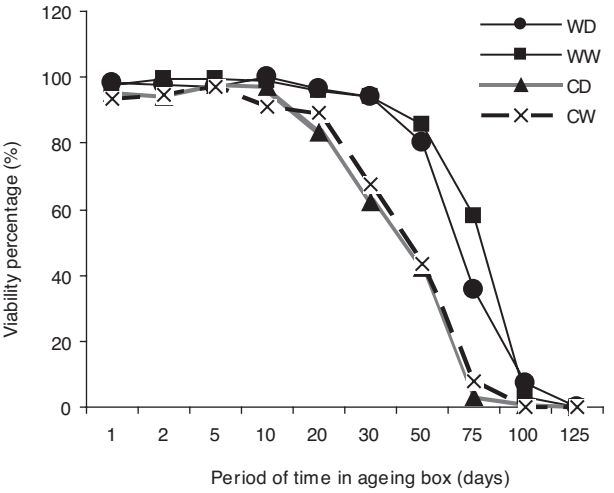

Figure 1. The viability (%) of seed lots measured over time in the laboratory-controlled ageing test. The seed had come from plants grown under four different production environments: Warm and Dry (WD), Warm and Wet (WW), Cool and Dry (CD) and Cool and Wet (CW).

DISCUSSION

The present data confirm the long-held belief that parthenium weed plants grown under a range of environmental conditions are able to produce vast amounts of seed (*c.* 21,500 per plant). However, this present study also shows that about half of this seed produced (*c.* 10,685 per plant) is unfilled and therefore, unable to germinate. The remaining seed is highly viable (with only *c.* 104 dead seeds per plant), able to germinate immediately under appropriate conditions, with a small but significant proportion of dormant seed (*c.* 780 seeds per plant) to aid long-term persistence in the soil seed bank. In addition, the number of dormant seeds produced under the two Cool conditions was very low (*c.* 125 per plant) compared with the huge number of seeds produced under the two Warm conditions (*c.* 1435 per plant). Clearly, dormancy was most effectively reduced in cold conditions and this is the same as reported by Karlsson et al. (2008) in an earlier study. The greater survival over time for the two Warm conditions indicates that Warm temperatures at the time of seed production enable the seed once shed to persist in the soil for >3 years. Cool temperatures at the time of seed production enable the seed once shed to persist in the soil for 1–3 years (Long *et al.* 2008).

In short, Warm conditions promote the reproductive ability of parthenium weed, such as increasing seed production and seed fill percentages, promoting dormant seed production and producing seed with the capacity to live longer in the soil seed bank.

ACKNOWLEDGMENTS

Operational funding for this research was provided by the Vietnamese Government (Project 322), the Queensland Murray Darling Committee and the University of Queensland.

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