Seed germination of *Opuntia stricta*: Implications for management strategies in the Kruger National Park

C.F. Reinhardt*[1], L. Rossouw[1], L. Thatcher[1] and W.D. Lotter[2]

[1]Department of Plant Production and Soil Science, University of Pretoria, Pretoria, 0002 Republic of South Africa
[2]Sappi Forests Divisional Head Office, Cascades, 3202 Republic of South Africa

Received 19 May 1999; revised 5 July 1999

The declared alien invader, *Opuntia stricta* (Haw.) Haw., is a serious pest in parts of the eastern Cape, northern Cape, Kwazulu-Natal, and Mpumalanga (in particular the Kruger National Park). To help with the development of an effective management strategy for the weed in the Kruger National Park (KNP), research on its biology and ecology was initiated with a study on seed germination. Seeds isolated from unripe, medium-ripe or ripe fruit were incubated at 20/15°C, 30/20°C or 35/25°C (day/night regimes; 12/12 h cycles). Germination was negligible at 20/15°C, while the optimum regime was 30/20°C. Averaged across temperature at final count (day 22) there were no significant differences in germination between seed from the three fruit classes, viz. 45, 40 and 48% for unripe, medium-ripe and ripe fruit, respectively. Seeds not used in the initial experiment were stored at room temperature for one year before germination was tested at 30/20°C and 27/17°C temperature regimes. Storage increased germination significantly to 79, 89 and 82% for seed from unripe, medium-ripe and ripe fruit, respectively, and neither the temperature nor the fruit class effect was significant. Long-term weather data for Skukuza (KNP) indicate that November–March is probably the peak period for germination of *O. stricta* seed. Results also suggest that control measures should be instituted, and the plants preferably killed, before fruit set occurs.

Keywords: Alien invader plant, germination, noxious weed, weed management.

*To whom correspondence should be addressed. (e-mail: charlie@scientia.up.ac.za).

Introduction

Opuntia stricta (Haw.) Haw. (common name: Australian pest pear) is a highly invasive species in arid and semi-arid areas. In this country it is listed as a declared weed according to the Conservation of Agricultural Resources Act (Act 43 of 1983), (Malan 1989). A native of southern and central America, the species was first recorded in Queensland, Australia, in 1843 (Johnson 1982). By 1913 it was spreading at a rate of 400 000 ha per year in that country and in 1925 more than 24 million ha were infested. The same invasive potential is being displayed by the species in the Kruger National Park (KNP). The first record of *O. stricta* in the KNP was made in 1953 and latest indications are that more than 30 000 ha of the KNP are infested of which about 2 000 ha are dense infestations (Lotter & Hoffmann 1998). The densest infestation is located near Skukuza rest camp where the personnel village, where the infestation is suspected to have originated (circa 1940's), is situated. The vegetation type in this area is the Sabie/Crocodile River thorn thickets (Gertenbach 1983).

Properties that confer noxious weed status on *O. stricta*, include: the ability to compete strongly with desirable species for growth resources, edible fruit and insignificant herbivory of vegetative parts (Wells *et al.* 1986). *Opuntia stricta* has a high water-use efficiency (Le Houerou 1996), but a low tolerance for cold temperatures (Luo & Nobel 1993). According to Malan (1989), terrestrial dry areas in moderate and sub-tropical rainfall areas meet the habitat requirements of *O. stricta* (Wells *et al.* 1986).

Opuntia spp. have many traits that contribute towards their pernicious nature (Benson 1983; Gregory *et al.* 1993; Dougherty *et al.* 1996). A seed property that would benefit their invasive nature is dormancy. According to Dodd (1940) seed of *Opuntia* spp. remain viable for approximately 15 years. There is relatively little information on the biology and ecology of *Opuntia* spp., particularly on the germination requirements of *O. stricta* seed. Without this information, prediction of the distribution patterns and impacts of the species on sensitive ecosystems would be tenuous. Studies on the fecundity of *O. stricta* and the viability and dispersal of seed are fundamental to assessments of the invasive potential of the species. Knowledge about these aspects would benefit the development of management strategies that are aimed at the containment/eradication of the species in the KNP.

The aims of the present study were to assess the influence, on the germination of *O. stricta* seed, of the following factors: (a) degree of fruit ripeness, (b) temperature, and (c) a post-harvest storage period.

Methods

Effect of temperature and degree of fruit ripeness on seed germination

During April 1996 *O. stricta* fruit at different stages of development, representing three degrees of ripeness, were collected near Skukuza in the KNP. Fruit were categorized and selected according to colour differences, i.e. unripe (green colour), medium-ripe (green with purple tinge) and ripe (dark reddish purple). Seeds removed from each type of fruit were handled and kept separately. The number of seeds per fruit varied between about 60 to 80, irrespective of fruit type. Seeds from unripe fruit had a light straw colour, whilst those from the two other fruit types were a darker, light-brown. Seeds were washed in running tap water to remove as much of the encapsulating fruit pulp as possible, and dried on paper towels at room temperature.

Further preparation of seeds for germination testing involved either treatment with hot water (24 h in water brought to boiling point), or with 10% (v/v) H_2SO_4 (40 minutes, then rinsed in water). Seeds were placed on germination paper, which was soaked with a waterbased suspension comprising the fungicides thiram and benomyl. The fungicides were applied at half-strength, based on the recommended rate for dry bean seeds (Krause, Nel & van Zyl 1996).

The paper rolls containing the seeds were incubated at three temperature regimes, which required the use of three growth chambers

Table 1 Germination of *Opuntia stricta* seed as a function of time, temperature regime[a] and the degree of fruit ripeness (Data are the percentage seed that germinated out of 50 seeds tested)

	Days after incubation started									
	4		6		8		10		12	
	Temperature regime (12/12 h period) degrees C (T)									
Degree of ripeness (R)	30/20°	35/25°	30/20°	35/25°	30/20°	35/25°	30/20°	35/25°	30/20°	35/25°
Ripe	8	0.6	14	8	20	8	24	12	30	18
Medium-ripe	6	1.0	10	8	14	10	20	14	24	22
Unripe	6	1.2	12	4	18	6	24	10	30	12
Mean	6.6	0.9	12	6.6	17	8	22	12	n/a	n/a
LSD_T	T × R = ns		T × R = ns		T × R = ns		T × R = ns		T × R = 10	
P = 0.05	T = 1.8		T = 3.0		T = 4.0		T = 4.0			

	Days after incubation started									
	14		16		18		20		22	
	Temperature regime (12/12 h period) degrees C (T)									
Degree of ripeness (R)	30/20°	35/25	30/20°	35/25	30/20°	35/25	30/20°	35/25	30/20°	35/25
Ripe	34	22	36	24	40	28	44	32	48	34
Medium-ripe	28	24	32	30	36	34	38	36	40	40
Unripe	34	14	38	18	40	22	42	24	45	26
LSD_T	T × R = 10		T × R = 8		T × R = 10		T × R 10		T × R = 10	
p = 0.05										

[a]Data for the 20/15°C regime are not presented due to negligible germination for this treatment

at the phytotron facility of the University of Pretoria. The three incubators were set at 35/25°C, 30/20°C and 20/15°C. Although the temperature regimes were set for 12/12 h periods in order to simulate day/night conditions, no lighting was provided and incubation was constantly in the dark. The paper rolls were periodically opened in the light to count seeds that had germinated.

The appearance of the radicle from seed was regarded as indicator of germination, and the number of seeds that germinated at each treatment was recorded every second day from the day the radicles first appeared. Fifty seeds were used per treatment combination and treatments were replicated three times.

Influence of post-harvest storage on seed germination

Seeds used were those left over from the initial experiment. They were kept for one year at room temperature in the dark. The germination tests were done as described above. The seeds were incubated in the dark at 30/20°C or 27/17°C (12/12 hour day/night cycles). Observations were made every second day. The paper rolls each contained 100 seeds, with three replicates for each treatment combination.

Analysis of variance (ANOVA) according to standard techniques was performed on data from both experiments. Treatment means were compared at the 5% (p = 0 05) level of significance according to the Least Significant Difference (LSD) test of Tukey.

Results

Effects of temperature and the degree of fruit ripeness on seed germination

Germination at the 20/15°C regime was virtually nil and, therefore, data from this treatment were not considered for statistical analysis and presentation. Since there were no significant differences in germination between seed batches treated with either hot water or diluted H_2SO_4, data presented below are averaged across these two treatments.

Data for the number of seeds germinated, from measurements made from day 4 when radicles first appeared until the day the experiment ended (day 22) appear in Table 1. From the fourth until the tenth day after germination was first noted, the main effect for temperature was the only significant effect. During that period, germination at 30/20°C was significantly greater than at 35/25°C (Table 1), and the stage of fruit development had no effect.

The Temperature × Fruit interaction effect first became significant on day 12 (Table 1). Prior to that day, germination at a particular temperature regime was independent of the stage of fruit development. But from day 12 until the end of the experiment on day 22, germination at 35/25°C of seed from unripe fruit was significantly less than that of the same seed kept at 30/20°C. At the latter temperature regime, seed from the three types of fruit showed similar germination.

Influence of post-harvest storage on seed germination

None of the treatment effects were significant. Germination percentages for stored seed was significantly higher in 1997 compared to the measurements made on the same seed batches in 1996 (Figure 1). The average total germination percentages of stored seeds from unripe, medium-ripe and ripe fruit were 79, 89 and 82%, respectively. The previous year, germination levels of 45, 40 and 48% were recorded. In this experiment, six days were required for germination to begin, whereas in the previous experiment, seeds started to germinate after four days of

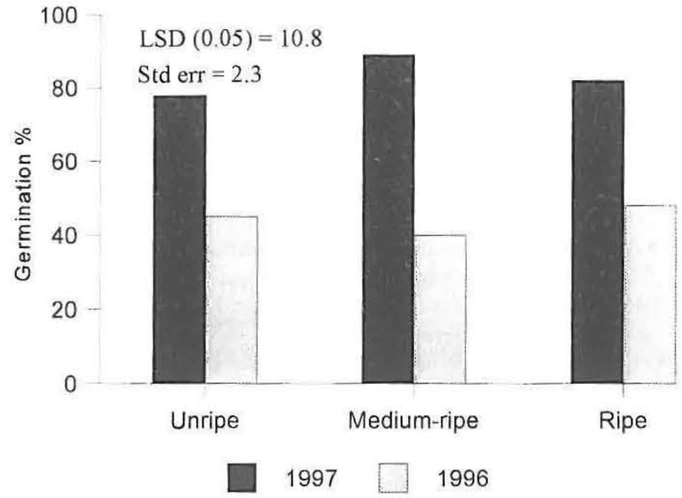

Figure 1 Germination of fresh seed collected in 1996 from unripe, medium-ripe or ripe fruit of *Opuntia stricta* and germination of seed from the same batches after a 1-year storage period (1997).

incubation.

Polyembriony (the development of two seedlings from a single seed) was observed at all three types of seed (unripe, medium-ripe and ripe fruit), at levels of 2.0%, 3.3% and 5%, respectively.

Discussion

Results suggest that the 30/20°C regime was optimal for seed germination. The fact that seeds from fruit of varying ripeness germinated equally well at the optimal temperature has important ramifications for control strategies. Findings suggest that chemical control of plants in the field should be done before fruit swelling occurs, i.e. spraying should not be delayed until fruits appear to mature, because seeds from unripe (green) fruit are also viable. The reason/s for the greater temperature-dependency for germination of seed from unripe fruit compared to seeds from either ripe or medium-ripe fruit are not apparent.

In contrast to present findings, Pilcher (1971) and Potter *et al.* (1984) found that an acid treatment increased seed germination of several *Opuntia* species. Our non-response result with the acid treatment suggests that an impermeable seedcoat was not the main factor governing germination, but rather an after-ripening requirement as indicated by increased germinability as a result of long-term storage.

Based on present results, and considering the long-term (10-year period) daily maximum/minimum temperatures for Skukuza (Swart 1996), it appears that temperatures during November to March may be most conducive for optimal germination of *O. stricta* seeds. The long-term average maximum/minimum regime for November to March at Skukuza is about 32/20°C. This period also spans the major part of the rainy season, which would further promote both germination and seedling establishment. Results suggest that relatively small temperature differences (± 5°C) may influence the germination of *O. stricta* seeds. Of course, in nature, temperatures fluctuate on an hourly basis and germination could be triggered when the optimal temperature is reached on a day for which the average regime may not be regarded as optimal. It is not known at this stage whether the duration of the optimal temperature is critical for germination and what its minimum duration should be. Also, daily temperature fluctuations may obviate dependence on a fixed optimum. Benson (1983) noted that 21°C was optimal for germination of various *Opuntia* spp. Another important factor to consider in arid and semi-arid environments is the availability of water. Both temperature and water should be at optimal levels before seed will germinate.

An interesting observation made during the study was the development of two seedlings from a single seed. The phenomenon of polyembrionic seeds has been reported for *O. ficus-indica* (Bewley & Black 1985) but apparently not for *O. stricta*.

Increased germination about a year after the collection of seed was probably the result of an after-ripening requirement that was met with storage of seed for a year. The methodology of the study precludes inferences about an after-ripening requirement. Potter *et al.* (1984) did report this phenomenon for *O. edwardsii*. Pilcher (1971) could not confirm the after-ripening requirement for *O. phaecantha* var. *discata*, although he did report slightly higher germination of *O. imbricata* after storage for one year. According to Potter *et al.* (1984), a period of four to seven days were necessary for germination to start, while maximum germination occurred only after two weeks or longer. This supports the germination pattern observed in the present experiment. In contrast, Timmons (1941) reported the onset of germination of several *Opuntia* spp. only five or six weeks after seeds were sown. Obviously, not only varietal differences but also the conditions under which experiments are performed, would affect seed germination.

The entire KNP (and most other areas of our country) should be regarded as vulnerable to invasion by *O. stricta*. Weather data for Skukuza for the past ten years suggest that November until March is the most favourable period for the germination of *O. stricta* seed. In view of the virtually zero germination recorded at 20/15°C, it appears that most seeds will not germinate in the KNP during periods when average day temperatures are below 20°C. This unfavourable condition will most likely occur during the greatest part of autumn/winter when the other important germination factor, water, is also in low supply.

Studies on the contribution of animals to the spread of this weed may be justified. It is imperative to avoid any fruit development if effective control of the weed is to be achieved. Therefore, control by means of herbicides should be done before fruit formation occurs. Practicalities obstructing the attainment of this management goal are manifest, even more so in the case of the complementary (to herbicides) management tool, biological control. Both these control practices (chemical and biological) are currently used for the management of *O. stricta* in the KNP where they have variable success. Present findings should be regarded as the start of much needed research on the biology and ecology of the species. With this knowledge, which eventually should incorporate the species' interactions with soil type and indigenous vegetation, it should be possible to improve existing management strategies for the control, and ideally, even the eradication of the species in targeted areas.

Acknowledgements

The University of Pretoria and the South African National Parks are thanked for their support of the project.

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