Role of fire on seed dissemination and germination of *Pinus pinaster* and *P. radiata*

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Abstract

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The genus *Pinus* is one of the most widely distributed on the planet. Within this, *P. pinaster* and *P. radiata* are two of the species that are also widely distributed, above all because of their recent use for reforestation. Fire is one of the environmental factors that most affects the natural and cultivated populations of *P. pinaster* and *P. radiata*. In this study we have analysed the effect of high temperatures on the opening of cones and germination of seed in both species, the effect of different concentrations of ash on the germination of their seeds, and the effect of the age of the seeds in combination with high temperatures and ash in the germinative response. We have found that the high temperatures cause the cones of *P. pinaster* and *P. radiata* to open without losing the viability of the seed. On the other hand, the high temperatures in the combinations of temperature and time exposure neither stimulate nor inhibit germination. Ash does inhibit germination to a certain degree if large amounts are applied. Finally, the age of the seeds has a different effect in each of the two species studied. In *P. pinaster* no significant differences were observed in the germination of seeds of different ages in any of the treatments applied. However, the oldest seeds from *P. radiata* showed lower germination values than seeds harvested more recently.

Key words: *Pinus pinaster*, *Pinus radiata*, fire, germination, dissemination.

Resumen

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El género *Pinus* es uno de los más ampliamente distribuidos del planeta. Dentro de éste, *P. pinaster* y *P. radiata* son dos de las especies con distribución también muy amplia, sobre todo por su reciente uso en repoblación forestal. El fuego es uno de los factores ambientales que más afecta a las poblaciones de *P. pinaster* y *P. radiata*, tanto naturales como cultivadas. En este trabajo hemos analizado el efecto de las altas temperaturas sobre la apertura de conos y germinación de semillas de ambas especies, el efecto de diferentes concentraciones de ceniza sobre la germinación de sus semillas y el efecto de la edad de las semillas en combinación con altas temperaturas y ceniza en la respuesta germinativa. Hemos encontrado que las altas temperaturas producen apertura de los conos de *P. pinaster* y *P. radiata* sin que las semillas pierdan su viabilidad. Por otro lado, las altas temperaturas en las combinaciones de temperatura y tiempo ensayadas no producen estimulación ni inhibición de la germinación. La ceniza sí produce cierto grado de inhibición de la germinación cuando la concentración aplicada es alta. Por último, la edad de las semillas ejerce un efecto diferente en cada una de las dos especies estudiadas. En *P. pinaster* no se observaron diferencias significativas en la germinación alcanzada por las semillas de diferente edad en
ninguno de los tratamientos aplicados, por su parte las semillas más viejas de *P. radiata* presentaron valores de germinación más bajos que las procedentes de cosechas más recientes.

**Palabras clave:** *Pinus pinaster, Pinus radiata*, fuego, germinación, diseminación.

**INTRODUCTION**

The genus *Pinus* is one of the most widely distributed on the planet. Twenty species have been described, naturally distributed in a wide range of environments in the Northern Hemisphere and among plantations in the Southern Hemisphere. Within this genus, two species that are present in the Mediterranean Basin are *P. pinaster* Aitón and *P. radiata* D. Don. The biogeographic region of *P. pinaster* corresponds with the West of the Mediterranean Basin and at present its principal populations are in the West of the Iberian Peninsula and the West of France, although its area of distribution occupies the Iberian Peninsula, France and Italy. Its preferred habitat is the Mediterranean coast, with Mediterranean and Atlantic climates (NICOLÁS & GANDULLO, 1969; RICHARDSON & RUNDEL, 1998).

*P. radiata* is found in a much smaller biogeographic region: California (USA) and Baja California (Mexico). However, its area of distribution has extended, via plantations, to many areas of Europe, Central America, Africa and Australia. The typical habitat of this species is the Mediterranean coast (GANDULLO et al., 1974; RICHARDSON & RUNDEL, 1998).

In all these climates, fire is a very common perturbation that acts on populations of these species. In general, pines do not normally have persistent seed banks in the soil, but they do have aerial seed banks, stored in their cones (LAMONT et al., 1991; LEONE et al., 2000; NATHAN & NÉEMAN, 2000). These two species are not able to sprout and so the probability that their population is restored after fire is directly related to the way in which the fire affects the dispersion and germination of the seeds.

We have centred our study on *P. pinaster* and *P. radiata*. Both species are present in the Mediterranean Basin where the incidence of fire is very high and we have tried to answer the following questions:

a) Are the high temperatures generated during a fire responsible for the opening of the cones?

b) Do the high temperatures affect seed germination?

c) Does the ash affect germination?

d) Does any relationship exist between the age of the seeds and their response to fire?

**MATERIAL AND METHODS**

In order to answer these four questions we have designed four independent experiments in which either seeds or complete cones of *P. pinaster* and *P. radiata* have been used.

**Opening of the cones**

In this experiment, 260 cones of both species were used. These were subjected to 26 different combinations of temperature and exposure time (five cones per treatment). The selected temperatures and exposure times cover a wide range of treatments within the possible combinations that can be produced during a forest fire (ESCUDERO et al., 1997; TRABAUD, 1980). These combinations of temperature and exposure times were the following: 500°C-1-min, 400°C-1-min, 350°C-1-min, 350°C-5-min, 300°C-1-min, 300°C-5-min, 300°C-10-min, 250°C-1-min, 250°C-5-min, 250°C-10-min, 250°C-15-min, 200°C-1-min, 200°C-5-min, 200°C-10-min, 200°C-15-min, 200°C-20-min, 150°C-5-min, 150°C-10-min, 150°C-15-min, 150°C-20-min, 150°C-25-min, 100°C-10-min, 100°C-15-min, 100°C-20-min, 100°C-25-min, 100°C-30-min.

**Effect of the high temperatures on germination**

In this experiment, seeds from *P. pinaster* and *P. radiata* were submitted to five thermal treatments and a Control. The combinations of
temperature and time exposure tested were the following: 90°C-1min, 90°C-5min, 110°C-1min, 110°C-5min y 150°C-1min. Six repetitions of 30 seeds each were performed for each one of the treatments and the control. The number of daily germinations produced during the first 46 days after sowing were counted. A more detailed explanation of the methodology used can be seen in Reyes & Casal (1995).

**Effect of the ash on germination**

In order to analyse the effect of the ash on germination of the seeds three dilutions of ash in water were tested (0.5g/L, 1g/L y 5g/L). The seeds were watered with these solutions in three of the treatments. In a fourth treatment (Ash), ash was applied directly to the seeds and afterwards they were watered with distilled water. In a fifth treatment (Control), only distilled water was added to the seeds. The amount of ash applied to each of the Petri dishes in the “Ash” treatment was 0.454g. The ash used in each case was produced from the combustion of needles and slender branches of individuals from each of the two species. As in the previous experiment, 6 repetitions of 30 seeds each were performed and were incubated for 46 days (see Reyes & Casal, 1998).

**Effect of the age of the seeds on their response to fire.**

In this experiment, the fire factors are considered to be: high temperatures and ash. For this reason, four fire treatments were selected: Control, 90°C-5min, 1g/L of ash in the water, and the effect of temperature and ash together. All these treatments were applied to seeds that had been stored during 1, 2, 3, or 4 years (Reyes & Casal, 2001). The seeds were incubated during 46 days and the number of germinations produced was noted daily. The number of repetitions and seeds per repetition is the same as in the previous two experiments.

**Statistical treatment**

In the first three experiments, ANOVAs were performed to check whether there were significant differences between the species and the treatments. An ANOVA was also applied in the fourth experiment and the factors analysed were: species, treatment and age of the seed. In those cases in which significant interactions between the analysed factors were detected, individual ANOVAs for each of the species were performed. When the ANOVA demonstrated the existence of significant differences between some of the factors analysed, the 95% reliability Tukey test was applied in order to find out the reason for the differences detected.

**RESULTS**

**Cone opening**

Comparing the results obtained in both species, we found that *P. pinaster* does not need such high temperatures or such a prolonged exposure time as *P. radiata* to open all or part of the scales of its cones (Fig. 1). However, the scale opening percentages registered for *P. pinaster* are below 60%, while the lowest value obtained in *P. radiata* is 87.45%, if the treatments of 220°C-1min and 100°C-10 min (in which no cones opened) are not taken into account.

We have detected a significant interaction between the factors species and treatment, for which reason each species was analysed separately. Significant differences between treatments were not detected in *P. pinaster*, but were detected in *P. radiata* (p<0.0001). These differences are due to the two treatments (200°C-1min and 100°C-10min) in which cone opening was not produced.

**Effect of the high temperatures**

The average germination percentage reached by *P. pinaster* is higher than that reached by the seeds of *P. radiata* (28.5% and 16.2%
Fig. 1. Percentage of open scales in each of the applied treatments to *P. pinaster* (in black) and *P. radiata* (in grey). Bars on columns represent the standard deviation. n=5 in all cases.

respectively). The individual germination percentages of each species for each treatment are shown in Fig. 2. In *P. pinaster*, the highest values for germination were obtained in the Control and 110°C-1min treatments (38.8 y 33.3%, respectively). The rest of the treatments showed slightly lower germination percentages of around 24%.

In *P. radiata*, the treatments that reached the highest germination values are Control and 90°C-1min with 20.0 and 22.7% respectively. The treatments with the lowest values are 110°C-5min (13.9%) and 150°C-1min (10.6%).

The ANOVA applied to the data from each of the species showed that there are no significant differences between the treatments in any of them.

**Effect of the ash on germination**

In this experiment, the average germination rate of *P. radiata* was a little higher than *P. pinaster* (55.5% compared to 41.8%).

Important differences were observed between the treatments applied to each of the two species, especially when comparing the “Ash” treatment with the rest (Fig. 3). This treatment, together with that of 5g/L in *P. radiata*, produces the lowest germination percentages.

The ANOVA applied to the germination data of both species detected highly significant differences (p<0.0001) between the species and between the treatments. With the Tukey test, it was proven that the only treatment that is significantly different to the others in *P. pinaster* is Ash, which only reaches 17.8% of germination against 48.88% in the Control treatment. The differences detected in the germination rate in *P. radiata* are due to the Ash (12.8%) and 5g/L (44.4%) treatments opposed to those of Control (72.8%), 0.5g/L (72.8%) and 1g/L (75.0%).

Therefore, the germination rate of both species decreases as the concentration of ash increases and this effect is more noticeable in *P. radiata* than in *P. pinaster*.

**Effect of seed age on their response to fire**

The germination values reached by *P. pinaster* and *P. radiata* vary in each species as a function of seed age and the fire treatment applied. The average germination percentage of *P. pinaster* was 54.5% and that of *P. radiata* 62.7%.
Fig. 2. Percentage of germination reached by *P. pinaster* and *P. radiata* in each of the applied temperature treatments. Bars on columns represent the standard deviation. n=6 in all cases.

Fig. 3. Percentage of germination reached by *P. pinaster* and *P. radiata* in each of the applied ash treatments. Bars on columns represent the standard deviation. n=6 in all cases. Values within the same species that are followed by the same letter are not significantly different at p<0.05.
In *P. pinaster*, the highest germination values correspond to the seeds from 1991 (57.5%), followed by those of 1993 (56.8%), 1990 (53.9%) and 1992 (50.0%). When the treatments that were applied are compared, the highest rates were observed in treatments of Ash and Ash+Temperature (Table I). The ANOVA applied to the data of *P. pinaster* did not detect significant differences between seeds of different ages or between treatments.

The seeds from *P. radiata* reached higher germination rates in the more recent collections. Thus, the germination percentage of 1993 seeds is 76.5%, in those from 1992 is 72.5%, in those of 1991 is 59.2% and in those of 1990 is 42.8% (Table I). The treatment that provides the highest germination rate is Control with 57.1% followed by Ash with 56.9%, Ash+Temperature with 54.4% and lastly Temperature with 49.7%.

The ANOVA applied to the data of *P. radiata* detected significant differences in the factor seed age (p<0.0001), but not in the factor treatment. According to the Tukey test the difference between the seeds of different ages is because the response of the seeds from 1993 and 1992 is different to the seeds from 1991 and 1990.

As a general pattern, the germination rate of *P. radiata* increases continually from 1990 to 1993, whilst in *P. pinaster* the germination values remain more or less constant.

### DISCUSSION

Traditionally it has been considered that species of the genus *Pinus* are well adapted to fire, despite the fact that most of them cannot sprout (Naveh, 1974; Trabaud, 1970, 1980).

In this study, we have proven that the high temperatures cause the cones to open in both *P. pinaster* and in *P. radiata*, but that the percentage of scales that open is different. *P. radiata* responds to higher temperatures or to prolonged exposure times and the final percentage of globally opened scales is also higher. This differentiated behaviour could be related to the area of origin of the species. *P. radiata* originated in California where the summer temperatures are high, the summer drought is hard, and fire frequency is high. *P. pinaster* originated in the western part of the Mediterranean Basin and lives as much in Atlantic as in Mediterranean climates. The *P. pinaster* seeds used in this study are from Atlantic populations and are probably not as well adapted to fire-prone environments as those of *P. radiata*.

With regard to the effect of high temperatures on germination, we have proven that high temperatures do not stimulate germination in any of the cases studied and that the differences that exist between the diverse treatments are due to chance.

In none of the cases does the effect of the ash stimulate germination. On the contrary, it inhibits
germination in the treatments with high quantities of ash. This inhibition increases in proportion to the increase in the concentration of ash applied.

In both species, the germination behaviour of seeds of different ages subjected to fire treatments was also different. The germination rates varied as a function of species and age of the seeds. The *P. radiata* seeds were more sensitive to the age factor than those of *P. pinaster*.

Similar behaviours to those found in this study have been detected by other authors in other species. With respect to the response of the seeds to high temperatures, MARTÍNEZ-SÁNCHEZ et al. (1995) proved in *P. halepensis* and *P. pinaster* subsp. *pinaster* that in no case did the high temperatures stimulate their germination. The same result was obtained by ESCUDERO et al. (1997) in *P. nigra* subsp. *salmannii* and in *P. sylvestris* var. *iberica*. We ourselves (REYES & CASAL, 1995) proved in *P. sylvestris* that high temperatures significantly reduced germination. ESCUDERO et al. (1997) also found that ash does not affect germination in *P. nigra* and *P. sylvestris*.

NE’EMAN et al. (1993) found that certain amounts of ash inhibit the germination of *P. halepensis*. Probably, both the response to high temperatures and to ash varies from one species to another depending on its sensibility to these factors. However, what appears to be proven is that neither the ash nor the high temperatures stimulate germination in some species of *Pinus*, but can inhibit this germination when the concentration of ash or the temperature to which the seeds are subjected is very high.

With respect to the effect that seed age has on germination after fire, there are still very few studies available for comparison of our results and probably the response is different in each species.

In conclusion, fire negatively affects germination in *P. pinaster* and *P. radiata* seeds. On the other hand, it favours cone opening of both species, facilitating the dispersion of numerous seeds. Forest fires create cleared environments where the availability of resources is greater (light intensity and the concentration of certain nutrients increase), competition is reduced and pressure from predators may also lessen (REYES & CASAL, 2002). It is this way, therefore, that is used by both species to abundantly regenerate their populations after fire.

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REFERENCES


