The Role of Combustion Products (Smoke) in Stimulating *Ex Situ* and *In Situ* Germination of Western Australian Plants

K.W. Dixon and S. Roche
Kings Park and Botanic Garden, West Perth, WA 6005

Smoke derived from the combustion of plant material enhances seed germination in a wide range of native species not previously able to be germinated under nursery conditions. Almost 100 species from the families Rutaceae, Restionaceae, Epacridaceae, Thymeleaceae, Proteaceae, Dilleniaceae, and others have responded under controlled nursery conditions to application of aerosol smoke and smoked water. Thirty species which responded have not previously been reported as easily germinable by conventional whole seed propagation, although some had previously (though partially) responded to scarification, boiling, or hormonal treatments. The effect of smoke is highly species-specific and influences seeds of the same species from disparate provenances and different ages to varying degrees. Genera known to be highly recalcitrant to conventional seed propagation which responded to smoke treatment included *Geleznowia* (Rutaceae), *Hibbertia* (Dilleniaceae), *Stirlingia* (Proteaceae), *Verticordia* (Myrtaceae), *Actinostrobus* (Cupressaceae), and *Pimelea* (Thymeleaceae). Germination percentages of species which normally germinate in small numbers were also positively influenced by smoke treatment. Seed size varied amongst all positively responding taxa. Within the Epacridaceae, small-seeded (*Lysinema* and *Sphenotoma*) but not larger, woody-fruited species showed smoke stimulated germination. Significant applications now exist for the use of smoke in germinating a wide range of species for horticulture and land restoration. Smoke appears to be one of the more significant missing links in understanding the horticulture of many Australian species. This technology is now opening up new opportunities for commercial horticulture of Australian plants.

INTRODUCTION

Fire has played a significant role in the evolution of the Australian flora at least since the arrival of arid conditions in the mid-Tertiary (Kemp, 1981). For many taxa, response to fire has moulded plant growth and development and been responsible for the derivation of analogous structures and life forms often in disparate taxonomic groups. In fire-prone floras, particularly those of mediterranean zones, fire has been shown to be crucial for the recruitment from seed of a wide variety of taxa. For fire-sensitive species and fire ephemerals, habitat burning is the single most important cue for triggering germination of the dormant soil seed bank (Bell et al., 1993; Meney et al., 1994). For many fire-responsive taxa, germination of viable seed under controlled conditions has been difficult or impossible using conventional treatments other than excised embryo culture (Meney et al., 1994) or special pretreatments including hormonal applications (Bell et al., 1993).

The Role of Smoke in Germination. Following the discovery that smoke stimulated germination of the rare South African plant *Audouinia capitata* (De Lange and Boucher, 1990) the exploration of the benefits of smoke-mediated germination has expanded to different continents with applications in nursery, land management, and rare-flora conservation.

As crude smoke or aqueous extracts applied to seed directly or to the surface of seed trays or as smoke to the soil surface in habitat sites, germination has been stimulated for a wide variety of species (Brown, 1993; Dixon et al., 1995).

The study of Dixon et al. (1995) found that smoke applied in a variety of ways was able to stimulate germination of Australian species both *in situ* (in bushland) and *ex situ* (nursery and laboratory). This study established for a wide range of species the importance of smoke as a cue for germination with resultant and sometimes spectacular improvements in germination.

This paper overviews development of smoke-stimulated germination of native Australian species and describes recent applications of the process for germination of horticulturally significant species.

Smoke-Stimulated Germination of Australian Species. Research by Dixon et al. (1995) has shown that smoke is a key principle in breaking seed dormancy in a wide variety of native Australian species. Though this study has concentrated on Western Australian plants, general principles have emerged regarding the benefits of smoke for germination:

- Smoke can promote earlier and more uniform germination under controlled greenhouse and laboratory conditions.
- Smoke enables germination in species previously thought difficult or impossible to germinate by conventional means, e.g.,*Geleznowia* and *Eriostemon* (Rutaceae); *Hibbertia* (Dilleniaceae); *Stirlingia* and*Conospermum*, *Grevillea*,and*Hakea* (Proteaceae);*Verticordia* and *Calytrix* (Myrtaceae); *Pimelea* (Thymeleaceae); *Blancoa* (Haemodoraceae); and *Stylidium* (Stylidiaceae).
- Smoke substantially promotes germination in species with low levels of germination. For example, *Anigozanthos* and *Conostylis* (Haemodoraceae); *Thysanotus* and *Burchardia* (Liliaceae); *Patersonia* (Iridaceae); *Lechenaultia* (Goodeniaceae); *Gyrostemon* and *Codonocarpus* (Gyrostemonaceae); *Stackhousia* (Stackhousiaceae); and *Hybanthus* (Violaceae).
- The promotive effect of smoke is independent of seed size and shape; plant life form, i.e., whether annual, perennial, herbaceous, seeder (fire sensitive) or resprouter (fire tolerant).
- Aerosol smoke, smoke dissolved in water or direct smoked solids (activated clays, sand particles) or direct smoked seeds are effective methods for delivery of smoke for seed germination.
- High doses of smoked water can inhibit germination of many species.
- Paper daisies (*Rhodanthe, Schoenia*) are suppressed by smoking.
- Germination over time in response to smoke can change with taxa, i.e., (1) Control and smoked seed attained final germination at the same rate, e.g., *Conostylis* species. (2) First seedling emergence occurred earlier in smoked seeds. (3) Control germination was

limited to first week or so whereas smoked seed continued to germinate over a longer period. (4) Difference between control and smoked treatment became apparent only after several weeks.

Species not responding to smoke treatment include *Persoonia* and drupaceous Epacridaceae (those species with large, woody fruits compared to small-seeded species which do respond positively to smoke). These groups have been extensively investigated to determine possible barriers to smoke entering the seed but all attempts to acid or mechanically scarify the seed have not been effective in eliciting a germination response. *Persoonia* has been found in other studies to respond to gibberellic acid treatments suggesting that factors involved in seed dormancy in this species may require other dormancy breaking mechanisms for germination to proceed.

SMOKE METHODS

Sown seed trays or whole seed are placed on an open mesh, two-tiered frame in a sealed, plastic tent approximately 2 m × 2 m × 1.4 m high. Smoke is generated by slow, controlled combustion of a mixture of fresh and dry leaf and twig material from a range of plants. Prunings of native species are usually used to emulate the natural smokes likely to occur after a wildfire in bushland habitats. The drum is fitted with an inlet through which air is pumped at the rate of 100 to 300 litres per min, and an outlet connected to a 1.5-m-long pipe. A 2-m length of flexible stainless steel exhaust piping approximately 50 mm in diameter is then connected to the plastic enclosure ensuring that smoke is injected towards the roof of the tent. This ensures that there is adequate spread of smoke inside the tent.

After smoking for 60 min, trays are transferred to the glasshouse and watered carefully for the first 6 to 10 days to ensure that the soluble promoter in smoke comes in contact with the seeds but is not washed through the mix before reacting with the seed. Watering is then continued as for normal germination.

Seeds can also be direct smoked. In this instance, seed is laid out in a single layer in trays. The trays are smoked for 60 min in the fumigation tent (as described above) and the air dried seed is then sown or stored dry until required. Smoked seeds are watered as with normal seed trays.

Smoked Water. Smoked water can be useful for direct priming or pregermination of seeds prior to sowing. Smoke-water-treated seeds have the advantage of not requiring the use of the smoke tent and the convenience of priming seeds at will. Smoke-water-primed seeds may germinate better than smoked seedling trays with the process applicable to handling potentially large quantities of seed such as, for land restoration or automated seed-sowing devices.

Smoked water is produced by drawing smoke produced from the combustion drum operating as for aerosol smoke through a 20-litre container of water. Smoke bubbling is done for approximately 60 min and the resultant solution is frozen till required.

Seed to be treated with smoked water is soaked for 12 h in a 10% solution of the neat solution and the seed is then sown or dried for later sowing. Seeds treated with smoked water can be watered normally after sowing. Although this method has been shown to be useful for a number of native species, caution is recommended as seed of some species can degenerate if soaked in water for prolonged periods. Also pregermination as a horticultural practise for seed of Australian native plants

requires some experimentation to ensure the process is applicable. In some cases pregermination can lead to decline in seed quality and viability and it is recommended that species to be treated in this way should be tested for tolerance to imbibing and drying treatments.

Habitat Germination Studies. Smoke fumigation treatments can be applied directly to habitat sites and for a range of species germination will happen in 6 to 8 weeks after treatment.

Smoke is generated as above and applied to sites where excess leaf litter and larger plants have been removed to prevent "shadowing" of the soil from smoke. Tents are erected over the sites—usually 5 m × 1 m × 40 cm high—and smoke pumped into the tent for 60 min. Best results are achieved if smoking is done in early autumn so that the wash down of the smoke factor coincides with the onset of the first rains (for temperate regions of Australia). Smoking undertaken at other times of the year appears to yield less germination for taxa which respond to autumn smoking.

Acknowledgements. This research was funded by the Minerals and Energy Research Institute of Western Australia, Rural Industries Research and Development Corporation, Land and Water Resources Research and Development Corporation with support from Alcoa Australia, RGC Mineral Sands, and wildflower growers and enthusiasts from around Australia.

LITERATURE CITED

Bell, D.T., J.A. Plummer, and **S.K. Taylor.** 1993. Seed germination ecology in Southwestern Western Australia. Bot. Rev. 59:24-73.

Brown, N.A.C. 1993. Promotion of germination of fynbos seeds by plant-derived smoke. New Phytol. 122:1-9.

de Lange, J.H. and **C. Boucher.** 1990. Autecological studies on *Audouinia capitata* (Bruniaceae). I. Plant-derived smoke as a seed germination cue. 5th. Afr. J. Bot. 56:700-703.

Dixon, K.W., S. Roche, and **J.S. Pate.** 1995. The promotive effect of smoke derived from burnt native vegetation on seed germination of Western Australian plants. Oecologia 101:185-192.

Kemp, E.M. 1981. Pre-quaternary fire in Australia, pp. 3-21. In: Fire and the Australian biota. Gill A.M., Groves R.H., and I.R. Noble (eds.) Australian Academy of Science, Canberra.

Meney, K.A., G.M. Neilssen, and **K.W. Dixon.** 1994. Seed bank patterns in *Restionaceae* and *Epacridaceae* after wildfire in kwongan in southwestern Australia. J. Veg. Sci. 5:5-12.