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OVERCOMING SEED DORMANCY OF *SENEGALIA GALPINII* AND *VACHELLIA ROBUSTA* THROUGH SCARIFICATION PRE-SOWING TREATMENTS

SUMMARY

The seeds of *Senegalia galpinii* (Burtt Davy) Seigler and Ebinger and *Vachellia robusta* (Burch.) Kyalangalilwa and Boatwright have hard coat-imposed dormancy that prevents water and air from entering the seeds, which is essential for the germination process. The specific objectives of this study were to determine the number of seeds per pod for the study species; determine the size and weight of seeds; and test the effects of scarification pre-sowing treatments on the speed, uniformity and total percent germination of seeds. Seeds of both species were subjected to 10 different pre-sowing seed treatments: the control, mechanical scarification, soaking in concentrated sulphuric acid (for 15, 30, 45 and 60 minutes), immersion in boiling water (for 1, 3 and 5 minutes), and soaking in boiling water (and cooling down for 24 hours). The germination data were examined using an analysis of variance and Tukey's honestly significant difference test to separate significantly different treatment means. The results showed that the mean number of seeds per pod was 7 ± 0.2 and 10 ± 0.03 for *S. galpinii* and *V. robusta*, respectively. For *S. galpinii*, the mean length, width and breadth of seeds were 12 ± 0.2, 10.4 ± 0.1 and 2.7 ± 0.03 mm, respectively. For *V. robusta*, the mean length, width and breadth of the seeds were 10 ± 0.1, 6.1 ± 0.1 and 4.2 ± 0.1, respectively. The mean thousand-seed weights were 275 ± 3 and 183.6 ± 6 g for *S. galpinii* and *V. robusta*, respectively. The results indicated that seeds treated with mechanical, sulphuric acid and boiling water scarification had significantly higher mean germination percentages than the controls for *S. galpinii*, whereas for *V. robusta*, mechanical scarification, exposure to sulphuric acid and immersion in boiling water and then cooling down for 24 hours yielded a better total percent germination than the controls. The highest mean germination percentages for *S. galpinii* (92–100%) were observed for seeds

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treated with sulphuric acid (15, 30, 45 and 60 minutes). For *V. robusta*, mechanical scarification resulted in the highest mean germination percentage (96%), and the boiling water treatments, except for the treatment with 24 hours of cooling down, resulted in the lowest mean germination percentage. The two study species possess seed-coat-imposed dormancies that require pre-sowing seed treatments. Based on the results, the best treatments to release dormancy in both *S. galpinii* and *V. robusta* are sulphuric acid and mechanical scarification, as these yielded the highest, fastest and most uniform germination of seeds. Appropriate recommendations are proposed.

Keywords: dormancy, germination percentage, pre-sowing treatments, seed size and seed weight.

INTRODUCTION

The socio-economic and ecological importance of forest resources and trees outside of forests is reflected in their contribution to livelihood diversification of rural and urban communities, wood and food security, animal feed, health care and environmental conservation (Teketay, 2004-2005). Despite the recognized socio-economic and ecological importance, forest resources and trees outside forests have been declining both in size (deforestation) and quality (degradation), especially in Africa, but also elsewhere in the world, over the past many years.

The major drivers of deforestation and forest degradation are clearing of forests and woodlands for cultivating crops and cutting of trees and shrubs for various purposes, notably for fuelwood, charcoal and construction materials. The fact that planted forests have been very far from meeting the demand for wood for various purposes indicates the inevitability of deforestation. The underlying causes of deforestation are, however, closely linked with the mutually reinforcing factors, i.e. poverty, population growth, poor economic growth and the state of the environment (Teketay, 2001, 2004-2005). Deforestation had caused and continues to cause environmental degradation in the form of land and water resources degradation as well as loss of biodiversity.

The rapid decline of the extent of natural forests has been a great concern in many African countries. Hence, there has been a continuous call by professionals and governments alike to plant trees or establish planted forests in order to address the huge demand of goods and services by both rural and urban communities. As a result, the goal of sustainable forest management has received considerable attention recently in international negotiations. The Rio Declaration (UNCED) and several of the United Nations conventions, as well as the United Nations Forum on Forests (UNFF) and other international processes, meetings and key publications have recognized the critical role of forest resources, including planted forests, in achieving sustainable development and mitigating the effects of climate change (Evans, 2009). The significance of planted forests and recognition of their contributions to a range of development goals are anticipated to increase in the coming decades. Planted forests provide not only wood, fibre and fuel, but also other non-wood forest products. Moreover, they sequester carbon, rehabilitate degraded lands, help in restoring landscapes, protect watersheds and agricultural soils, and provide recreational areas and amenities.

The study species, namely *Senegalia galpinii* (Burtt Davy) Seigler and Ebinger (synonym: *Acacia galpinii* Burtt Davy) and *Vachellia robusta* (Burch.) Kyalangalilwa and Boatwright (synonym: *Acacia robusta* Burch.), are among the excellent candidates for establishing planted forests because of their multi-purpose uses and very fast growth. However, similar to many other members of the Fabaceae, their seeds possess hard seed coats that are impermeable to water, hence, prevent germination. Seed coat impermeability has been reviewed by several authors (Ballard, 1973; Tran and Cavanagh, 1984; Cavanagh, 1987; Egley, 1989) while its ecological significance has been discussed by Fenner (1985), Baskin and Baskin (1989), Gutterman (1993) and Bewley and Black (1994). Seed coat imposed dormancy is a delaying mechanism, which prevents germination under conditions, which might prove to be unsuitable for establishment, thereby, distributing germination both in time and space (Teketay, 1996a, b, 2005). This, in turn, increases the chances that some seeds will successfully germinate to complete the life cycle. The ability to remain dormant for a long period is associated with seeds of species from unpredictable environments and climate, with very variable rainfall trends, such as those found in Botswana, where most of the *Senegalia* and *Vachellia* species grow.

A high level of seed dormancy is a characteristic feature of many plants of dry regions, and it either completely prevents germination or allows very few seeds to germinate over a long period of time. Therefore, to obtain rapid, uniform and high germination, the dormancy imposed by the hard seed coat should be removed. Lack of knowledge of the germination requirements of leguminous species is an obstacle for their successful artificial regeneration (Teketay, 1996a, b; Mojeremane et al., 2017, 2018; Odirile et al., 2019; Setlhabetsi et al., 2019). Different scarification techniques, such as mechanical, acid and boiling/hot water scarification have been widely used (Teketay, 1996a, b, 1998, 2005; Aref et al., 2011; Tadros et al., 2011; Missanjo et al., 2014; Rasebeka et al., 2014; Fredrick et al., 2016) because they can improve germination by overcoming seed dormancy within a relatively short period of time (Tadros et al., 2011; Mojeremane et al., 2017; 2018; Odirile et al., 2019; Setlhabetsi et al., 2019). But, no single pre-treatment method has been reported to be effective across plant species (Amusa, 2011).

Apart from seed dormancy, seed size, including weight, is an important component in plant fitness, and it is thought commonly to be an important focus of selection on the life histories of plants (Janzen, 1977; Saeed and Shaukat, 2000) since the likelihood of dispersal, germination and survival can all depend on seed size (Howe and Kerckhove, 1980; Schaal, 1980; Saeed and Shaukat, 2000). Studies have shown significant effects of seed size within a species on percent germination (Milberg and Andersson, 1994), rate of germination

(Marshall, 1986), seedling size (Zhang and Maun, 1990) and seedling competitive ability (Gross, 1984). Seed size can show considerable variation within population, and this variability is often associated with variability in seedling size (Schaal, 1980). The individual seed size (mass) in a species varies from nearly constant (Fenner, 1985) to as high as 16-fold (Thompson and Pellmyr, 1989). In general, large seeds have a higher seedling survival rate, higher growth and better field performance than small seeds (Ambika *et al*. 2014; Steiner *et al*., 2019).

Despite the practical importance, there is no information on the numbers of seeds per pod, seed sizes (length, width and breadth), single seed masses and thousand seed weights of both *S. galpinii* and *V. robusta*.

Therefore, the general objective of this study was to determine characteristics of seeds and identify the best scarification seed treatments that result in the fastest and highest as well as uniform germination of the two study species. The specific objectives of the study were to: (a) determine the number of seeds (intact, eaten/dead and aborted seeds) of the study species per pod; (b) determine the size (length, width and breadth) and weight (mass of single seeds and thousand seed weight) of seeds; and (c) test the effects of scarification seed treatment methods (pricking, sulphuric acid and boiling/hot water) on the speed, uniformity and total percentage germination of seeds of the study species.

MATERIAL AND METHODS

Study site

The seeds used in the study were collected in Gaborone, Botswana, located at 24° 39' 11.7252" S and 25° 54' 24.4512" E. It is located at about 15 km away from the South African border. The city lies at an elevation of 994 m (Odirile et al., 2019) and has a hot semi-arid climate, usually with hot summers and sunny days all year round.

Study species

Senegalia galpinii (Burtt Davy) Seigler and Ebinger

The species is also commonly known as the monkey-thorn (English) and mokala, mophoka and mpungwane (Setswana) (Setshogo and Venter, 2003). Monkeys like taking cover in its wide branches and may also eat the pods and seeds, hence, the common name. The tree is fast-growing, reaching 25-30 m, and deciduous, losing its leaves during the southern African winter from April to July. It has a yellowish-brown fissured bark, which is flaking in thin papery pieces as well as short, broad and hooked prickles. Its creamy to light yellow flowers appear during the growing season from September to October and the reddish to purplish brown pods ripen during February to March (Mutshinyalo, 2003).

The species grows naturally in open, wooded grassland, open woodland and often near streams. The trees can survive hot and dry conditions (Mutshinyalo, 2003). The species is indigenous to northern and eastern Botswana, Malawi, South Africa, Zambia, and Zimbabwe (Mutshinyalo, 2003; van Wyk and van Wyk, 2011).

Many insects, such as bees, and wasps visit the flowers. The ripe pods burst open, releasing the seeds, and the seeds are also dispersed by animals eating the pods. In the wild, the plant is grazed and used for shade during the hot summer by different animals including giraffes, kudus and elephants. Many birds often prefer nesting in this tree as it provides protection. The tree makes a stunning tree along roads where there is enough space. It also provides shade on hot summer days, making it an ideal tree for planting on a lawn where some sun can penetrate (Mutshinyalo, 2003). The strong black hooked thorns are ideal for making security hedge (Timberlake, 1980; Venter and Venter, 2013). The roots are burnt and used to cure headaches while dried and crushed pods are used for ear infections, heated pods are used for swellings, wood ash is used to sooth wounds, and the root infusions are used as cough medicine (van Wyk and van Wyk, 2011).

Vachellia robusta (Burch.) Kyalangalilwa and Boatwright

Vachellia robusta is known by the common names: broadpod robust thorn, false umbrella thorn and splendid acacia (English) as well as moga, moku and moshaoka (Setshogo and Venter, 2003). It is represented by fast-growing small to medium-sized trees, reaching 10 m (usually around 5 - 8 m) high, with a slightly flattened crown. The main stem is grey to blackish with rough hairy branches. The white thorns are straight and paired. The leaves are twice-compound with 2 - 5 pairs of pinnae and 10 - 15 pairs of dark green and glossy leaflets. The flowers are creamy white, which are produced from July to October, followed by the dehiscent greyish brown, straight and broad pods, adorning the tree from November to August (Mokobori and Hankey, 2015).

The species occurs in a diverse range of habitats and is component of many plant communities. The species is commonly found in open forests and woodlands, often near streams, where one can find large specimens. In southern Africa, it is very common in the warm dry savannas, up to 1,800 m altitude. It is resistant to drought and frost. It is distributed from tropical Africa southwards to Namibia, eSwazini, Ethiopia, Mozambique, Somalia and South Africa. It has also been introduced elsewhere, e.g. in South Asia (Mokobori and Hankey, 2015).

Leaves are browsed by kudu and other mammals. The strongly scented flowers attract bees and butterflies, and many other insects. The pods and leaves are eaten by herbivores, which distribute the seed in their dung. The seeds are parasitized by Bruchid beetle larvae, which eat the developing seed. Many birds will rifle through the dry seed pods looking for these beetle larvae. Birds, such as Sparrows and Finches, like to build their nests in the densely thorny branches of the trees since the thorns offer excellent protection from predators (Mokobori and Hankey, 2015). The species is modulated by nitrogen-fixing Rhizobium soil bacteria, which colonize inside the roots, where they fix atmospheric nitrogen, which is unavailable to plants and convert it to ammonia (Mokobori and Hankey, 2015).

The wood is considered of rather poor quality, but is sometimes used for making furniture and shelving. It is also used as firewood. The pulping properties of the wood have been rated as good. In traditional medicine, the powdered root is applied to swellings, and a decoction of the roots is used to treat dysmenorrhea (pain during menstruation), infertility in women and bilharzia (schistosomiasis), whereas a decoction of the stem bark is used to treat gonorrhoea, abdominal pain and skin conditions. The leaves are used to treat snake bites. The species is commonly grown as an attractive garden tree and occasionally grown as a bonsai. The trees can provide a spectacular display when flowering and are very good garden trees, even in frost-prone regions (Timberlake, 1980; Lemmens, 2006; van Wyk and van Wyk, 2011; Mokobori and Hankey, 2015).

Methods

Number of seeds in a pod

The number of seeds of the two study species in a pod were determined from five replications of 10 pods each. The seeds were, then, categorized as intact, aborted or dead/eaten. Once extracted from pods, seeds were immersed in cold water, and only those that sank and settled at the bottom of the container were used for the experiment. The floated seeds, which represented non-viable seeds, were discarded.

Size and weight of seeds

The sizes, i.e. length, width and breadth of seeds, of the two study species were determined by measuring five replications of 10 seeds each using a digital calliper.

The weight of single seeds (seed mass) was determined by weighing five replicates of 10 seeds using a digital sensitive scale. Similarly, five replications of 100 seeds from each study species were weighed to determine the weight of thousand seeds.

Experiments and treatments

In this study, three experiments containing 10 treatments, including the control, were carried out. The three experiments were mechanical scarification, exposure to sulphuric acid and exposure to boiling water. The treatments in the experiments were completely randomized in four replications.

Experiment 1 - Mechanical scarification

In this experiment, 100 seeds of each study species, with four replications of 25 seeds, were used. In all these seeds, 1-2 mm of the seed coat was removed using scissors so that the seeds could imbibe water, which is required to initiate germination.

Experiment 2 - Exposure to sulphuric acid

In this experiment, four periods of exposure of seeds of the study species, i.e. 15, 30, 45 and 60 minutes, to concentrated sulphuric acid (98%) were used by employing the method described by Teketay (1996a). For each period of exposure, the four replications of 25 seeds were put into four 100 ml heat-resistant non-corrosive glass beakers containing sulphuric acid by making sure that all the seeds were covered by the acid. The seeds were continuously stirred to ensure their uniform exposure to the acid. After the specified periods of exposure, the seeds were sieved out of the acid using an acid-resistant sieve while the acid was drained off simultaneously into another beaker. The seeds were, then, thoroughly washed and rinsed to remove all the acid in a running tap water and distilled water, respectively.

Experiment 3 - Exposure to boiling water

In this experiment, three periods of exposure of seeds of the study species, i.e. 1, 3 and 5 minutes, to boiling water were used. For each period of exposure, four replications of 25 seeds were put into four separate coffee filter papers and immersed into a cooking pot with boiling water for the specified period, after which they were removed and immersed in a small bucket containing cold distilled water to cool them down for a few minutes.

Four replications of 25 untreated seeds were used as control for all the experiments. In all the experiments and the control, each replication containing the 25 seeds were enclosed in 8 mm petri dishes lined with cotton wool. The cotton wool was continuously kept moist by adding distilled water whenever necessary until the end of the experiments. Seeds were considered to have germinated when the radicle penetrated the seed coat and reached 1 - 2 mm. The germinated seeds were counted and recorded on daily basis. The germinated seeds were removed from petri-dishes after counting and recording. The experiments were terminated after 30 days. Seeds that had not geminate after 30 days were tested for their viability by a cutting test.

Data analyses

The data collected was subjected to both descriptive statistics and One-Way ANOVA using Statistix Software, Version 10 (Statistix 10, 1984-2003). Before the ANOVA, the germination percentage data were arcsine transformed to meet the requirement of normality (Zar, 1996). Significant differences of means were tested using Tukey's Honestly Significant Difference (HSD) at the significance level of $P < 0.05$.

RESULTS

Status of number of seeds in a pod

The mean numbers of seeds per pod were 7 ± 0.2 and 10 ± 0.3 in *S. galpinii* and *V. robusta*, respectively. Of these, the mean numbers of intact, eaten and aborted seeds in S. galpinii were 6 ± 0.3, 4 ± 0.1 and 1.2 ± 0.1, respectively. In the case of V. robusta, the mean numbers of intact, eaten and aborted seeds were 7 ± 0.4, 1 ± 0.2 and 2 ± 0.2, respectively (Table 1).

Single and thousand seed weights

The mean mass of single seeds of *S. galpinii* and *V. robusta* was 0.269 ± 0.007 and 0.197 ± 0.0008 grams, respectively. Similarly, the mean thousand seed weights were 275 ± 3 and 183.6 ± 6 grams for *S. galpinii* and *V. robusta*, respectively.

The highest mean germination (100 and 98%) for *S. galpinii* were those from seeds treated with sulphuric acid (30, 45, 60 and 15 minutes), followed by those treated with mechanical (88%) and boiling water (85%, allowed to cool in

24 hours) and boiling water (15 minutes, 74%) while the control and boiling water (3 and 5 minutes) were not significantly different from each other (Table 3).

Table 1. Status (intact, eaten and aborted) and number of seeds pod^{-1} of the study species (mean values ± standard error of means).

Species	Status and Number of Seeds							
	Intact		Eaten		Aborted		Total	
	Number	Range	Number	Range	Number	Range	Number	Range
Senegalia galpinii	6 ± 0.3	1 – 10	0.4 ± 0.1	0 – 4	1.2 ± 0.1	0 - 4	7.4 ± 0.2	4 – 11
Vachellia robusta	7 ± 0.4	0 – 12	1 ± 0.2	0 - 4	2 ± 0.2	0 - 9	10 ± 0.3	3 – 14

Size of seeds

The mean length, width and breadth of *S. galpinii* seeds were 12 ± 0.2, 10.4 ± 0.1 and 2.7 ± 0.03 mm, respectively. For *V. robusta*, the mean length, width and breadth of the seeds were 10 ± 0.1, 6.1 ± 0.1 and 4.2 ± 0.1, respectively (Table 2). Seeds of *S. galpinii* were longer and wider than those of *V. robusta* while *V. robusta* exhibited more breadth than *S. galpinii*.

Table 2. Seed size (mm) of the study species (mean values ± standard error of means).

Species	Size of Seeds (mm)					
	Length	Range	Width	Range	Breadth	Range
Senegalia. galpinii	12 ± 0.2	12 – 13	10.4 ± 0.1	10.2 – 10.7	2.7 ± 0.03	2.7 - 2.9
Vachellia robusta	10 ± 0.1	9.6 - 10	6.1 ± 0.1	6 – 6.4	4.2 ± 0.1	4 – 4.4

Germination of seeds

The results indicated that the seeds treated with mechanical, sulphuric acid and boiling water scarification had significantly higher mean germination percentages than the controls in the two study species *[S. galpinii* - One Way ANOVA: (F (9, 39) = 34, P = 0.00001) and *V. robusta* - One Way ANOVA: (F (9, 39) = 33, P = 0.00001)] (Table 3).

For *V. robusta*, the mechanical scarification had the highest mean germination (96%), followed by those treated with sulphuric acid for 60 and 45 minutes (86 and 72%, respectively) and boiling water for 24 hours (70%). Untreated seeds (34%) and those treated with boiling water for 1 (24%), 3 (12%) and 5 (6%) minutes exhibited the lowest mean germination percentages (Table 3).

Table 3. Means and ranges of the cumulative germination of seeds of the study species subjected to different pre-sowing seed treatments (± standard error of the means).

Treatment	*S. galpinii*		*V. robusta*	
	Germination (%)	Range (%)	Germination (%)	Range (%)
Control	9 ± 10^{d}	4 - 24	34 ± 6de	24 - 52
Mechanical Scarification	88 ± 11^{abc}	72 - 96	96 ± 2^{a}	92 - 100
Sulphuric Acid (15 minutes)	92 ± 6^{abc}	88 - 100	32 ± 6de	16 - 44
Sulphuric Acid (30 minutes)	100 ± 0^{a}	100 - 100	52 ± 6^{cd}	40 - 68
Sulphuric Acid (45 minutes)	98 ± 4^{ab}	92 - 100	72 ± 8^{bc}	52 - 88
Sulphuric Acid (60 minutes)	98 ± 4^{ab}	92 - 100	86 ± 4^{ab}	76 - 96
Boiling Water (1 minute)	74 ± 16^{c}	60 - 88	24 ± 3^{def}	16 - 28
Boiling Water (3 minutes)	39 ± 13^{d}	24 - 52	12 ± 5^{ef}	0 - 20
Boiling Water (5 minutes)	23 ± 12^{d}	16 - 40	6 ± 3^{f}	0 - 12
Hot Water (boiling water allowed to cool in 24 hours)	85 ± 4^{bc}	80 - 88	70 ± 8^{bc}	56 - 84

Means separated using Tukey's Honestly Significant Difference (HSD) Test at $P \leq 0.05$. Means within columns followed by the same letters for each species are not significantly different.

Rate of Seed Germination

The results revealed that seeds of *S. galpinii* that were exposed to sulphuric acid and mechanical scarification exhibited the fastest and uniform germination, reaching > 91% and > 85% cumulative germination, respectively, within six days after sowing followed by those treated with hot water and boiling water for 1 minute, reaching > 71% and > 66% within six days (Figure 1), respectively.

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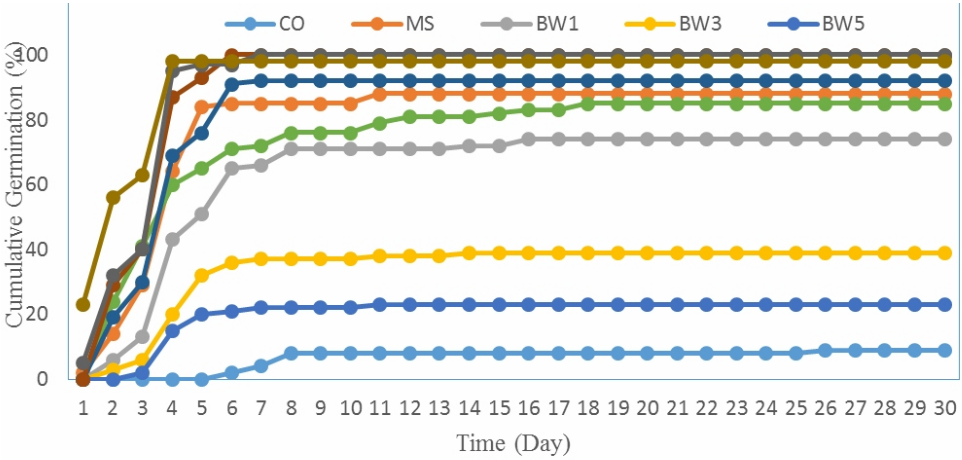

Figure 1. Cumulative germination percentage of *Senegalia galpinii* recorded for 30 days (CO = Control, MS = Manual scarification, BW1 = Boiling water for 1 minute; BW3 = Boiling water for 3 minutes, BW5 = Boiling water for 5 minutes, HW24 = Boiling water allowed to cool in 24 hours, SA15 = Sulphuric acid for 15 minutes, SA30 = Sulphuric acid for 30 minutes, SA45 = Sulphuric acid for 45 minutes and SA60 = Sulphuric acid 60 minutes).

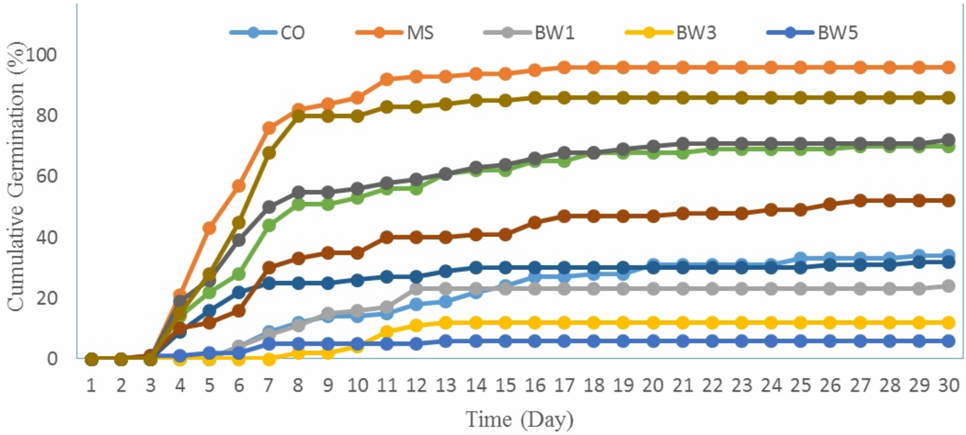

Figure 2. Cumulative germination percentage of *Vachellia robusta* recorded for 30 days (CO = Control, MS = Manual scarification, BW1 = Boiling water for 1 minute; BW3 = Boiling water for 3 minutes, BW5 = Boiling water for 5 minutes, HW24 = Boiling water allowed to cool in 24 hours, SA15 = Sulphuric acid for 15 minutes, SA30 = Sulphuric acid for 30 minutes, SA45 = Sulphuric acid for 45 minutes and SA60 = Sulphuric acid 60 minutes).

On the other hand, untreated seeds (control) and seeds treated with boiling water for 3 and 5 minutes exhibited not only the lowest, but also the slowest germination.

The results also showed that in the case of *V. robusta*, seeds treated with mechanical scarification and sulphuric acid for 60 minutes exhibited the fastest and uniform seed germination, reaching >82% and >80% cumulative germination, respectively, within eight days (Figure 2). On the other hand, seeds treated with boiling water for 1, 3 and 5 minutes exhibited, not only the lowest, but also the slowest germination

DISCUSSION

It has been demonstrated that seed size, represented by length, width, breadth and weight, is a life history trait that may affect the fitness of parent plants and the population regeneration process (Harper *et al*., 1970; Harper, 1977; Fenner, 1985; Gross and Kramer, 1986; Silvertown, 1989; Chacon *et al*., 1998; Finch-Savage and Bassel 2016; Steiner *et al*., 2019). This implies that seed size affects the germination, emergence, plant growth and performance of plants in the field. It has been shown that plants from large seeds had larger and more leaves, greater plant weight and more vigour than plants from small seeds (Elliott *et al*., 2007). Large seeds have been shown to exhibit higher germination and emergence than small seeds and produce larger and more vigorous seedlings, which may enhance survivorship (Hendrix, 1984; Sikder *et al*. 2009; Steiner *et al*., 2019).

Seeds of *S. galpinii* exhibited longer and wider, but less broad, seeds as well as heavier single seed masses and thousand seed weights than those reported for *V. robusta* (Table 2) and *V. rehmanniana* Schinz. Similarly, *V. robusta* had longer and broader, but comparable width of seeds with *V. rehmanniana* (Mojeremane et al., 2017). Seeds of *S. galpinii* were longer and wider than those of *Vachellia erioloba* (E. Mey.) P.J.H. Hurter, but *V. erioloba* exhibited longer and wider seeds than those of *V. robusta* as well as broader and comparably broader seeds than *S. galpinii* and *V. robusta*, respectively (Odirile et al., 2019). Both *S. galpinii* and *V. robusta* exhibited longer, wider and broader seeds as well as much heavier single seed masses and thousand seed weights than several other similar leguminous species, e.g. *V. tortilis* (Forssk.) Galasso and Banfi (Odirile, 2018), *Dichrostachys cinerea* (L.) Wight and Arn., *Senegalia erubescens* (Welw. ex Oliver) Kyal. and Boatwr. and *Vachellia nilotica* (L.) Delile (Kahaka et al., 2018), *Peltophorum africanum* Sond. (Mojeremane *et al*., 2018), *Sesbania bispinosa* (Jacq.) W. Wight (Mafote, 2018), and other species, e.g. *Ziziphus mucronata* Willd. (Malatsi, 2019). The large seeds possessed by both *S. galpinii* and *V. robusta* would confer advantages of having higher germination, as evidenced in this study, and emergence as well as developing larger and more vigorous seedlings, which ensure higher survival in the field.

Most evidences (Tran and Cavanagh, 1984; Cavanagh, 1987; Egley, 1989) implicate that the continuous layer of tightly packed palisade cells in the seed coat as containing the major barrier to water entry into seeds. Therefore, rupture of the seed coat is necessary to trigger germination in many hard-seeded species with impermeable seed coats (Ballard 1973; Baskin and Baskin 1989; Bewley and Black 1994; Rolston 1978; Teketay, 2005). Hence, seeds have to be pre-treated before sowing to overcome the hard seed-coat imposed dormancy that will stimulate water imbibition and their germination. Among the different pre-sowing seed treatments, scarification using mechanical removal of the seed coats (about 2 mm) and exposure of seeds to different durations in sulphuric acid are known to be consistently effective, resulting in rapid, uniform and high germination in different species (Cavanagh, 1987). For some species exposure of seeds to different durations in boiling water has also been shown to increase germination (Teketay, 1996a, b, 1998, 2005).

In the present study, scarification of seeds of *S. galpinii* with mechanical means, sulphuric acid and boiling water resulted in better germination percentages (23 - 100%) than the untreated seeds (control = 9%). Similarly, seeds of *V. robusta* seeds treated with mechanical scarification, sulphuric acid and boiling water (allowed to cool for 24 hours = 70%) (duration = 30, 45 and 60 minutes) exhibited better germination percentages (52 - 96%) than those in the control (34%). However, seeds of *V. robusta* treated with sulphuric acid (for 15 minutes = 32%) and boiling water (for 1, 3 and 5 minutes) showed lower germination percentage (6 - 24%) than the control, suggesting that these treatments are not effective to improve germination of seeds significantly since the seeds were sensitive to high temperatures.

The present study confirms results from earlier seed germination studies on other leguminous species, e.g. species of *Acacia* (Larsen, 1964; Clemens et al., 1977; Bebawi and Mohamed, 1985; Sniezko and Gwaze, 1987; Danthu et al., 1992; Masamba, 1994; Teketay, 1996a; Tadros et al., 2011), *Afzelia* and *Baikiaea* (Botsheleng, *et al*., 2014), *Albizia* (Babeley *et al*., 1986; Msanga and Maghembe, 1986; Khan and Tripathi, 1987; Teketay *et al*., 1996a, 2018), *Cadaba* (Teketay, 1996a), *Caesalpinia* (Ngulube, 1989; Teketay, 1996a), *Erythrina* (Teketay, 1994) and *Leucaena* (Oakes, 1984; Babeley and Kandaya, 1985; Duguma et al., 1988; Teketay, 1996a; Tadros et al., 2011), *Calliandra* and *Sesbania* (Albrecht, 1993), *Entada*, *Delonix* and *Prosopis* (Teketay, 1996a), *Faidherbia* (Fredrick *et al*., 2016), *Vachellia* and *Peltophorum* (Mojeremane et al., 2017; Mojeremane et al., 2018; Kahaka et al., 2018; Odirile et al., 2019), *Dicrostachys* and *Senegalia* (Kahaka et al., 2018), and *Philenoptera* (Setlhabetsi et al., 2019), which demonstrated that scarification of seeds through mechanical, sulphuric acid and boiling water pre-sowing treatments improved germination.

In the natural habitat, fire (Dell, 1980; Sabiiti and Wein, 1987), animal ingestion (Lamprey et al., 1974; Russi et al., 1992; Gardener et al., 1993), abrasion (Gutterman, 1993), soil acids and soil organisms (Bewley and Black, 1994) as well as fluctuating temperatures (Probers, 1992) have been implicated to be responsible for breaking seed coat-imposed dormancy. Moist heat, mimicked by boiling water in the present study, has also been reported to improve germination (Martin et al., 1975; Jeffery et al., 1988). Moist heat is thought to simulate more nearly conditions in a forest fire since moisture is available from thermal degradation and combustion of woody fuels and from moisture present in the fuels (Teketay, 2005). Fire is an annual recurrent phenomenon across many habitats in Botswana, including forests and woodlands. Therefore, heat generated from fire may act as one of the factors stimulating germination.

Pods of *S. galpinii* (Mutshinyalo, 2003) and *V. robusta* (Mokobori and Hankey, 2015) are browsed by different animals. Hence, passage of the hard seeds through the digestive tracts of animals may be another means by which their scarification is effected making them ready for germination when they are dispersed in the dung of animals. The diurnal fluctuation of temperature between day and night may also be another factor which stimulates germination in the natural habitats.

CONCLUSIONS

Results from the present study show that the barrier to germination of seeds of *S. galpinii* and *V. robusta* is the hard seed coat, which prevents water uptake. Hence, before the seeds can germinate, they require mechanisms, which overcome this barrier. The results also indicated that the barrier can be removed through different scarification pre-sowing treatments. For *S. galpinii*, mechanical scarification as well as exposure to sulphuric acid and boiling water significantly improved percent germination of seeds while for *V. robusta* only mechanical scarification, exposure to sulphuric acid and immersing the seeds in boiling water, which was allowed to cool down for 24 hours, gave better percent germination than the untreated seeds. The results also confirmed that sulphuric acid and mechanical scarification treatments resulted in the highest, fastest and uniform germination percentages relative to the control and boiling water treatments.

Therefore, extension agents and researchers that have plans to raise seedlings of *S. galpinii* and *V. robusta* should undertake scarification treatments using mechanical scarification, sulphuric acid and boiling water (only for *S. galpinii*), before sowing the seeds in order to render the seed coats permeable to water and trigger germination. Mechanical scarification and boiling water treatments are recommended for nurseries since they are safer and require less skill to administer while sulphuric acid treatments can be used in research laboratories.

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REFERENCES

Albrecht J. 1993. Tree seed handbook of Kenya. GTZ forestry seed centre, Kenya Forest Research Institute, Muguga.

Ambika S, Manonmani V and Somasundaram G. 2014. Review on effect of seed size on seedling vigour and seed yield. Research Journal of Seed Science, 7(2): 31-38.

Amusa T. 2011. Effects of pre-treatment techniques on dormancy and germination of seeds of *Afzelia africana*. Journal of Horticulture and Forestry, 3(4): 96-103.

Aref IM, Atta HAE, Shahrani TA and Mohamed AI. 2011. Effects of seed pre-treatment and seed source on germination of five *Acacia* spp. African Journal of Biotechnology, 10(71):15901-15910.

Babeley GS, Gautam SP and Kandya AK. 1986. Pretreatment of *Albizia lebbeck* Benth. seeds to obtain better germination and vigour. Journal of Tropical Forestry, 2: 105-I 13.

Babeley GS and Kandya AK. 1985. Effect of various pretreatments on germination and vigour of *Leucaena leucocephala* (Lam.) de Wit seeds. Journal of Tropical Forestry, 1: 85-90.

Ballard LAT. 1973. Physical barriers to germination. Seed Science and Technology, 1: 285-303.

Baskin JM and Baskin CC. 1989. Physiology of dormancy and germination in relation to seed bank ecology. In: Leck MA, Parker VT, Simpson RL. (eds.) Ecology of Soil Seed Banks. Academic Press, San Diego, pp. 55-66.

Baskin JM and Baskin CC. 2004. Classification systems for seed dormancy. Seed Science Research, 14: 1-16.

Bebawi FF and Mohamed SM. 1985. The pretreatment of seeds of six Sudanese acacias to improve their germination response. Seed Science and Technology, 13: 111-l 19.

Bewley JD and Black M. 1994. Seeds: Physiology of Development and Germination (2nd ed.). Plenum Press, New York and London.

Botsheleng B, Mathowa T and Mojeremane W. 2014. Effects of pre-treatments methods on the germination of Pod mahogany (*Afzelia quanzensis*) and mukusi (*Baikiaea plurijuga*) seeds. International Journal of Innovative Research in Science Engineering and Technology, 3(1):8108-8113.

Cavanagh T. 1987. Germination of hard-seeded species (Order Fabales). In: Langkamp P (ed.), Germination of Australian Native Plant Seed. AMIRA, Melbourne/Sydney, pp. 58-70.

Chacon P, Bustamante R and Henriquez C. 1998. The effect of seed treatment on germination and seedling growth of *Cryptocarya alba* (Lauraceae) in Chile. Revista Chilena de Historia Naturel, 71: 189-197.

Clemens J, Jones PG and Gilbert NH. 1977. Effects of seed treaments on germination in *Acacia*. Australian Journal of Botany, 25(3): 269-276.

Danthu P, Rousse M, Dia M and Sarr A. 1992. Effect of different pretreatments on the germination of *Acacia Senegal* seeds. Seed Science and Technology, 20: 11l-l 17.

Dell B. 1980. Structure and function of the strophiolar plug in seeds of *Albizia lophantha*. American Journal of Botany, 67: 556-563.

Duguma B, Kang BT and Okali DUU. 1988. Factors affecting germination of *Leucaena leucocephda* (Lam.) de Wit. Seed Science and Technology, 16: 489-500.

Egley GH. 1989. Water-impermeable seed coverings as barriers to germination. In: Taylorson RB (ed.), Recent Advances in the Development and Germination of Seeds. Plenum Press, New York, pp. 207-223.

Elliott RH, Mann LW and Olfert OO. 2007. Effects of seed size and seed weight on seedling establishment, seedling vigour and tolerance of summer turnip rape (*Brassica rapa*) to flea beetles, Phyllotreta spp. Can. J. Plant Sci., 87: 385-393.

Evans J. 2009. Planted Forests: Uses, Impacts and Sustainability. CABI and Food and Agriculture Organisation of the United Nations, Rome, Italy.

Fenner M. 1985. Seed Ecology. Chapman and Hall, London.

Finch-Savage WE and Bassel GW. 2016. Seed vigour and crop establishment: extending performance beyond adaptation. Journal of Experimental Botany, 67(3): 567-591.

Fredrick C, Muthuri C, Ngamau K and Sinclair F. 2016. Provenance and pre-treatment effect on seed germination of six provenances of *Faidherbia albida* (Delile) A. Chev. Agroforestry Systems, doi:10.1007/s10457-016-9974-3.

Gardener CJ, Mclvor JG and Jansen A. 1993. Passage of legume and grass seeds through the digestive tract of cattle and their survival in faeces. Journal of Applied Ecology, 30: 63-74.

Gross KL. 1984. Effects of seed size and growth form on seedling establishment of six monocarpic perennial plants. Journal of Ecology, 72: 369-387.

Gross KL and Kromer ML. 1986. Seed weight effects on growth and reproduction of *Oenothera biennis* L. Bulletin of the Torrey Botanical Club, 113(3): 252-258.

Gutterman Y. 1993. Seed Germination in Desert Plants. Springer-Verlag, Berlin.

Harper JL. 1977. Plant Population Biology. Academic Press, London.

Harper JL, Lovell PH and Moore KG. 1970. The shapes and sizes of seeds. Annual Review of Ecology and Systematics, 1: 327-356.

Hendrix SD. 1984. Variation in seed weight and its effects on germination in *Pastinaca sativa* L. (Umbelliferae). American Journal of Botany, 71(6): 795-802.

Howe HF and Kerckhove GAV. 1980. Nutmeg dispersal by tropical birds. Science, 210: 925-927.

Janzen DH. 1977. Promising directions of study in tropical animal-plant interactions. Ann. Missouri Bot. Garden, 64: 706-736.

Jeffery DJ, Holmes PM and Rebelo AG. 1988. Effects of dry heat on seed germination in selected indigenous and alien legume species in South Africa. S. Afr. Tydskr. Plantkd., 54: 28-34.

Kahaka P, Mojeremane W, Teketay D and Mathowa T. 2018. Effects of Scarification Treatments on Seed Germination of Three Leguminous Species from Botswana. Silva Lusitana, 26(1) (in press).

Khan ML and Tripathi RS. 1987. Ecology of forest trees of Meghalaya: seed germination, and survival and growth of *Albizia lebbeck* seedlings in nature. Indian Journal of Forestry, 10: 38-43.

Lamprey HF, Halvey G and Makacha S. 1974. Interactions between *Acacia bruchid* seed beetles and large herbivores. East African Wildlife Journal, 12: 81-85.

Larsen E. 1964. Germination response of *Acacia* seeds to boiling. Australian Journal of Forestry, 1: 51-53.

Lemmens RHMJ. 2006. *Acacia robusta* Burch. In: Louppe D, Oteng-Amoako AA, Brink M (eds.). PROTA (Plant Resources of Tropical Africa / Ressources végétales de l'Afrique tropicale), Wageningen, Netherlands [https://uses.plantnet-project.org/en/Acacia_robusta_(PROTA), accessed on 10-10-2018].

Mafote T. 2018. Reproductive attributes that promote the invasion of *Sesbania bispinosa*. Botswana University of Agriculture and Natural Resources, Gaborone, Botswana.

Malatsi S. 2019. The Effects of Provenances and Pre-Sowing Seed Treatments on Germination of Seeds of *Ziziphus mucronata*. Botswana University of Agriculture and Natural Resources, Gaborone, Botswana.

Marshall DL. 1986. Effect of seed size on seedling success in three species of Sesbania (Fabaceae). American Journal of Botany, 73: 457-464.

Martin RE, Miller RL and Cushwa CT. 1975. Germination response of legume seeds subjected to moist and dry heat. Ecology, 56: 144-1445.

Masamba C. 1994. Presowing seed treatments on four African *Acacia* species: appropriate technology for use in forestry for rural development. Forest Ecology and Management, 64: 105-109.

Milberg P and Andersson L. 1994. Effect of emergence date on seed production and seed germinability in *Thlaspi arvense*. Swedish Journal of Agricultural Research, 24: 143-146.

Missanjo E, Chioza A and Kulapani C. 2014. Effects of different pre-treatments to the seed on seedling emergence and growth of *Acacia polyacantha*. International Journal of Forestry Research, http://dx.doi.org/10.1155/2014/583069.

Mojeremane W, Mathowa T and Teketay D. 2018. Effects of different pre-sowing treatments on germination of *Peltophorum africanum* Sond. seeds from two provenances in Botswana. Journal of Biodiversity and Environmental Sciences, 12(2): 230-236.

Mojeremane W, Mathowa T, Teketay D, Stimela T, Kopong I and Rampart M. 2017. Pre-sowing seed treatment method to overcome dormancy in seeds of *Vachellia rehmanniana* Schinz. Agriculture and Forestry, 63(2): 171-181.

Mokobori T and Hankey A. 2015. Vachellia robusta (Burch.) Kyalangalilwa and Boatwright subsp. robusta. Walter Sisulu National Botanical Garden, South Africa (http://pza.sanbi.org/vachellia-robusta-subsp-robusta, accessed on 19-12-2019).

Msanga HP and Maghembe JA. 1986. Effect of hot water and chemical treatments on the germination of *Albizia schimperana* seed. Forest Ecology and Management, 17(2-3): 137-146.

Ngulube MR. 1989. Seed germination, seedling growth and biomass production of eight central American multipurpose trees under nursery conditions in Zomba, Malawi. Forest Ecology and Management, 27: 21-27.

Mutshinyalo T. 2003. *Senegalia galpinii* (Burtt Davy) Seigler and Ebinger. Pretoria National Botanical Garden, South Africa (http://pza.sanbi.org/senegalia-galpinii, accessed on 19-12-2019).

Oakes AJ. 1984. Scarification and germination of seeds of *Leucaena leucocephala* (Lam.) de Wit. Tropical Agriculture (Trinidad), 61: 125 -127.

Odirile O. 2018. Responses of seeds of two *Vachellia* species from Botswana to different pre-sowing treatments. Botswana University of Agriculture and Natural Resources, Gaborone, Botswana.

Odirile O, Mojeremane W, Teketay D, Kashe K and Mathowa T. 2019. Responses of seeds of *Vachellia erioloba* (E. Mey.) P.J.H. Hurter in Botswana to different pre-sowing treatment methods. International Journal of Biology and Biotechnology, 16(1): 181-188.

Probers RJ. 1992. The role of temperature in germination ecophysiology. In: Fenner M (ed.). Seeds: The Ecology of Regeneration in Plant Communities. C.A.B. International, Wallingford, pp. 285-325.

Rasebeka L, Mathowa T and Mojeremane W. 2014. Effect of seed pre-sowing treatment on germination of three *Acacia* species indigenous to Botswana. International Journal of Plant and Soil Science, 3(1): 62-70.

Russi L, Cocks PS and Roberts EH. 1992. The fate of legume seeds eaten by sheep from a Mediterranean grassland. Journal of Applied Ecology, 29: 772-778.

Sabiiti EN and Wein RW. 1987. Fire and *Acacia* seeds: a hypothesis of colonization success. Journal of Ecology, 74: 937-946.

Saeed S and Shaukat SS. 2000. Effect of Seed Size on Germination, Emergence, Growth and Seedling Survival of *Senna occidentalis* Link. Pakistan Journal of Biological Sciences, 3: 292-295.

Schaal, B. A. 1980. Reproductive capacity and seed size in *Lupinus texensis*. American Journal of Botany, 67: 703-709.

Setlhabetsi OT, Mojeremane W, Mathowa T and Teketay D. 2019. Breaking seed dormancy in *Philinoptera violacea* (Koltzsch) Schire using different pre-sowing treatment methods. Journal of Agriculture and Environmental Sciences, 8(1): 104-110.

Setshogo MP and Venter F. 2003. Trees of Botswana: names and distribution. Southern African Botanical Diversity Network Report No. 18., Pretoria, South Africa.

Sikder S, Hasan MA and Hossain MS. 2009. Germination characteristics and mobilization of seed reserves in maize varieties as influenced by temperature regimes. Journal of Agricultural and Rural Development, 7(1-2): 51-56.

Silvertown JW. 1989. The paradox of seed size and adaptation. Trends in Ecology and Evolution, 4: 24-26.

Sniezko RA and Gwaze DP. 1987. Effect of seed treatments on germination of *Acacia albida* Del. In: Kamra SK and Ayling RD (eds.). Proceedings of the International Symposium on Forest Seed Problems in Africa. Department of Forest Genetics and Plant Physiology, Swedish University of Agricultural Sciences, Umeå, pp. 325-333.

Statistix 10. 1985-2013. Statistics 10 for Windows. Tallahassee, Florida, USA.

Steiner F, Zuffo MA, Busch A, Sousa TDO and Zoz T. 2019. Does seed size affect the germination rate and seedling growth of peanut under salinity and water stress? Pesq. Agropec. Trop., Goiânia, 49, e54353: 1-9.

Tadros MJ, Samarah NH and Alqudah AM. 2011. Effect of different pre-sowing seed treatments on the germination of *Leucaena leucocephala* (Lam.) and *Acacia farnesiana* (L.). New forests, 42(3):397-407.

Teketay D. 1996a. Germination Ecology of twelve indigenous and eight exotic multipurpose leguminous species from Ethiopia. Forest Ecology and Management, 80: 209-223.

Teketay D. 1996b. The effects of different pre-sowing seed treatments, temperature and light on the germination of five *Senna* species from Ethiopia. New Forests, 155-171.

Teketay D. 1998. Germination of *Acacia origena, A. pilespina* and *Pterolobium stellatum* in response to different pre-sowing seed treatments, temperature and light. Journal of Arid Environments, 38(4): 551-560.

Teketay D. 2001. Deforestation, wood famine and environmental degradation in highland ecosystems of Ethiopia: urgent need for action. Northeast African Studies, 8: 53-76.

Teketay D. 2004-05. Causes and consequences of dryland forest degradation in Sub-Saharan Africa. Walia, 24: 3-20.

Teketay D. 2005. Seed and regeneration ecology in dry Afromontane forests of Ethiopia: I. Seed production - population structures. Tropical Ecology, 46: 29-44.

Thompson JN and Pellmyr O. 1989. Origins of variance in seed number and mass: Interaction of sex expression and herbivory in *Lomatium salmoniflorum*. Oecologia, 79: 395-402.

Timberlake J. 1980. Botswana Acacias. Ministry of Agriculture, Gaborone, Botswana.

Tran VN and Cavanagh AK. 1984. Structural aspects of dormancy. In: Murray DR (ed.), Seed Physiology, Vol. 2, Germination and Reserve Mobilization. Academic Press, Sydney, pp. l-44.

van Wyk B and van Wyk B. 2011. Photo guide to trees of Southern Africa. Briza Publication, Pretoria, South Africa.

Venter F and Venter J. 2013. Making the Most of Indigenous Trees. Briza Publication, Pretoria, South Africa.

Zar JH. 1996. Biostatistical Analysis. Prentice Hall, Englewood Cliff, New Jersey, USA.

Zhang J and Maun MA. 1990. Seed size variation and its effects on seedling growth in *Agropyron psammophilum*. Bot. Gazette, 151: 106-113.