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Full Length Research Paper

Effects of seed pretreatment and seed source on germination of five *Acacia* spp.

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The effects of seed pre-sowing treatment and geographic source of seeds on three germination parameters of five *Acacia* species (GP = germination percent; GMT = germination mean time (days) and GI = germination index) were studied. Pre-sowing treatment included immersion in concentrated sulphuric acid for 5, 10 and 15 min; immersion in hot water for 2, 4 and 6 min; abrasion of the seed coat and control. Seeds were collected from three geographical regions in the Kingdom of Saudi Arabia (Aseer and Al Baha regions in South-Western and Al Madinah region in the West). Experiments were carried out on Petri dishes containing moistened filter papers and incubated in a growth chamber. Seed pretreatment significantly (P < 0.0001) affected GP, GMT and GI in all tree seed species studied. Generally, scarification (acid and mechanical abrasion) resulted in the best GP, GMT and GI. Hot water also gave good germination for most tree seed species. Germination behavior of *A. ehrenbergiana* seeds was different compared to other species. More also, increasing the time of immersion in acid decreased the GP in seeds collected from both Aseer and Al Baha regions, while in contrast, *A. origena* germinated better with increasing time of immersion in acid and hot water. Geographic source of seeds significantly affected most germination parameters, although it was comparatively inconsistent compared to seed treatment. Highly significant interactions (P < 0.0001) were recorded between seed pretreatment and seed source.

Key words: *Acacia species*, pretreatment, seed source, germination, scarification, hot water.

INTRODUCTION

Acacia spp. is widely distributed in arid and semi-arid regions. The genus Acacia is the most important tree-component of the flora in Saudi Arabia (Demel 1996; Wilson and Witkowski, 1998; Aref et al., 2003). Acacias are currently attracting great interests due to their drought resistance (Oba et al., 2001) and multiple uses such as fodder, wood and non-wood products (gums, resins and pharmaceuticals) for the local communities, provision of shade and live fencing (Noad and Birnie, 1989) and in maintaining soil fertility through nitrogen fixation (Belsky et al., 1989). It is also well known that *Acacia* species are very important sources for the provision of non-wood products in arid and semi-arid environments (Kassa et al., 2010). Most *Acacia* spp have hard seed coats impervious to water (Demel, 1996; Baskin and Baskin, 1998; Walters et al., 2004). This causes seed dormancy so that germination may extend over months or years, hence it is necessary to pre-treat the seeds prior to sowing to maintain maximum and rapid germination. The nature of seed coat impermeability is however, not fully understood, although it is has been suggested that water penetration occurs at the strophiole. This is considered as the weakest area of the seed coat and it is a small raised area close to the hilum on the side opposite the micropyle (Cavanagh, 1980a).

Naturally, seed dormancy was thought to provide a better chance for the establishment of seedlings under more favorable conditions in an attempt to guarantee growth and survival of young seedlings (Carvalho and Nakagawa, 2000). It is high time we promoted affo-restation and reforestation programmes to mitigate the alarming increase in deforestation especially in arid lands. FAO (2007) estimated worldwide deforestation at

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Table 1. Climate in the study areas (2000 to 2011).

Region	Temperature (℃)			Rainfall (mm)		Elevation (m.a.s.l.)
	Monthly mean maximum	Monthly mean minimum	Mean monthly	Monthly mean maximum	Mean monthly	
Aseer	31.2	7.6	19.2	115.2	11.8	2093.35
Al Baha	36.1	9.9	23.2	132.3	9.2	1651.88
Al Madinah	44.3	11.3	28.9	63.4	2.9	635.6

Source: National Metrological and Environmental Center, Presidency of Meteorology and Environmental Protection, Ministry of Defense and Aviation, Kingdom of Saudi Arabia.

13 million ha or 0.7% of the total forested area annually. Germination process is considered as the most important and crucial factor in a plant life cycle as it seriously affects successful execution of afforestation and reforestation programmes (Vibekke et al., 2004; Bu et al., 2008). Numerous techniques have been used to render mainly *Acacia* and some other seeds are permeable, including scarification, as well as soaking in tap water, boiling or hot water, acids, organic solvents and alcohols (Bonner et al., 1974; Clemens et al., 1977; Zwaan, 1978; Delwaulle, 1979; Cavanagh, 1980a; ISTA, 1981; Ren and Tao, 2004; Patane and Gresta, 2006; Okunomo and Bosah, 2007; Kassa et al., 2010).

However, studies of the relationship between seed source and germination have been conflicting (Stelling et al., 1994; Tapscott and Cowling, 1995; Burnett et al., 1997; Perin et al., 2002). This study was therefore undertaken to study the effect of seed pretreatment and geographic source on germination parameters.

MATERIALS AND METHODS

Seed collection and preparation

The seeds of *Acacia asak* Forssk., *A. etbaica* Schweunf, *A. ehrenbergiana* Hayne, *A. gerrardii* Benth. and *A. origena* Asfaw were collected directly from standing trees during May to June 2010, from three geographical regions in Saudi Arabia (Aseer, Al Baha and Al Madinah) (Table 1). In Aseer region, the seeds of *A. asak, A. ehernbergiana* and *A. etbaica* were collected from Tihama Gahtan (1749165N, 4224422E); *A. gerrardii* from Al-Marbaa ((1754055N, 4226511E) and *A. origena* from Al-Masga National Park (17640553N, 4228523E). In Al Baha region, the seeds of *A. asak*, were collected from Al Mekhwat (50530N, 4136476E); *A. etbaica, A. ehernbergiana* and *A. gerrardii* from Alagig (1949613N, 4134380E) and *A. origena* from Ghimda (1949613N, 4135280E). In Al Madinah region, the of seeds *A. ehernbergiana* were collected from Wadi Alrimth (24155389N, 3916936E). Seeds were extracted manually and broken, then infected seeds were discarded, while intact seeds were air-dried and sorted at room temperature (24 to 26℃) to keep the seeds viable for the germination experiments.

Seed treatment and scarification

A total of 100 seeds of each species from each region were treated as follows: (1) mechanical scarification: seeds of each species from each region were scarified manually by cutting 1 mm of the seed coat at the opposite site of hilum by scissors; (2) chemical scarification: seeds were soaked in concentrated sulphuric acid (98%) for 5, 10 and 15 min, respectively, after which the seeds were thoroughly rinsed in tap water and distilled water, and finally air-dried; (3) hot water: seeds were soaked in boiling distilled water at 100℃ and left for 2, 4, and 6 min, respectively, inside a 100 ml flask; (4) control: seeds were not treated.

Germination experiments

A total of 25 seeds were placed on three layers of Whatman filter paper No. 3 in 9 cm Petri dishes. Four replicates were used for each treatment plus the control. Filter papers were kept moistened and distilled water was added whenever needed throughout the duration of the experiments. Germination experiments were carried out in a completely randomized block design with two factors (seed treatment and seed source). Petri dishes were kept in a growth chamber (Weiss Technik) at a constant temperature (30 ± 1℃) and 12/12 h light and darkness. Germination was monitored daily and recorded. Seeds were considered germinated when the healthy, white radical had emerged through the integument.

Determination of germination parameter

The following germination parameters were determined:

(1) Germination percentage (GP); the number of germinated seeds as a percentage of the total number of tested seeds is given as;

GP = (germinated seeds/total tested seeds) × 100 %

(2) Germination mean time, is given according to Scott et al. (1984) as;

(GMT days): $= \sum T_i N_i / S$

Where T_i is the number of days from the beginning of the experiment, N_i the number of seeds germinated per day and S is the total number of seeds germinated.

(3) Germination index (GRI): it was calculated for each treatment using the following Equation:

$GRI = (G_1/1) + (G_2/2) + ... + (G_x/x)$,

Where G is the germination day 1, 2…, and x represents the corresponding day of germination (Esechie, 1994).

Statistical analysis

The following statistical analyses were used: ANOVA was used to

Table 2. Effect of seed pretreatment on germination of the five *Acacia* spp. (Aseer region) (ANOVA).

Species	Parameter	Source	DF	SS	MS	F value	P	R^2 (%)
A. asak	GP	Model	7	16071.54	2295.93	15.61	< 0.0001	80.18
		Error	27	3971.43	147.09			
	GMT (days)		7	59.49	8.49	12	< 0.0001	75.68
			27	19.12	0.71			
	GI		7	583.76	83.39	76.81	< 0.0001	95.72
			24	26.06	1.08			
			24	648.51	27.02			
A. ehrenbergiana	GP		7	26156.8	3736.68	25.42	< 0.0001	85.99
			29	4262.22	146.97			
	GMT (days)		7	132.32	18.9	13.52	< 0.0001	76.67
			29	40.25	1.39			
	GI		7	214.14	30.59	33.49	< 0.0001	88.99
			29	26.49	0.91			
A. etbaica	GP		7	26206.88	3743	56.21	< 0.0001	91.19
			38	2530.85	66.6			
	GMT (days)		7	87.13	12.44	31.54	< 0.0001	85.31
			28	14.99	0.39			
	GI		7	437.51	62.5	91.72	< 0.0001	94.41
			38	25.89	0.68			
			38	426.08	15.78			
A. gerrardii	GP		7	21680.94	3097.28	46.6	< 0.0001	92.62
			26	1728	66.46			
	GMT (days)		7	41.74	5.96	11.41	< 0.0001	75.44
			26	13.59	0.52			
	GI		7	130.3	18.61	45.63	< 0.0001	92.47
			38	10.6	0.41			
			27	250.01	9.25			
A. origena	GP		7	19229.49	2747.07	22.69	< 0.0001	84.11
			30	3632.4	121.08			
	GMT (days)		7	66.87	9.55	16.98	< 0.0001	79.84
			30	16.88	0.56			
	GRI		7	130.3	18.61	45.63	< 0.0001	92.47
			26	10.6	0.41			
			27	246.87	9.14			

GP = Germination (%); GI = germination index; GMT = germination mean time (days).

test the effect of seed treatments and LSD was used for mean separation. T-tests and ANOVA were also used to test the effect of seed source, while GLM was used to test the interaction between seed treatments and seed source. All statistical analyses were carried out using SAS statistical package (SAS, 1997).

RESULTS

Effect of seed treatment on germination (Aseer region)

For *A. asak*, seed pretreatment significantly ($P < 0.0001$) affected GP, GMT and GI (Table 2) in all the tree seed species studied. Scarified seeds and seeds treated with concentrated sulphuric acid at all concentrations produced maximum GP (92.0 to 96.0%) as compared to hot water immersion (60 to 72%) and control seeds GP (38.28%) which had the lowest GP (Table 2). The trend was more or less similar for GMT and the control seeds, which recorded almost double the GMT (5.92 days) as compared to other treatments (Table 2). GI was significantly maximum after scarification (12.9) and at 15 min immersion in concentrated sulphuric acid (12.89) (Table 3).

For *A. ehrenbergiana*, GP was significantly ($P < 0.05$) higher in scarified seeds, seeds treated with concentrated sulphuric acid for 5 and 10 min and seeds immersed in hot water for 4 min, while the control seeds recorded the

Table 3. Effect of seed pretreatment on mean germination parameters of the five *Acacia* species (Aseer region).

Species	Parameter	Treatment							
		A5	A10	A15	H2	H4	H6	S	C
	GP	93.0^{a}	93.0^{a}	92.0^{a}	66.0^{b}	60.0^{b}	72.0^{b}	96.0^{a}	38.2^{c}
A. asak	GMT (days)	3.27^{ab}	2.76^{a}	2.27^{a}	4.74^{b}	4.13^{b}	3.33^{ab}	2.35^{a}	5.92^{c}
	GI	8.16^{b}	9.29^{b}	12.8^{a}	3.71^{d}	4.24^{d}	7.12^{c}	12.9^{a}	1.56^{e}
	GP	94^{a}	88^{a}	64^{b}	88^{a}	97^{a}	49^{b}	98^{a}	31.5^{c}
A. ehrenbergiana	GMT (days)	5.09^{a}	4.53^{a}	3.4^{a}	3.98^{a}	4.35^{a}	4.98^{a}	3.69^{a}	8.55^{b}
	GI	5.23^{b}	5.68^{b}	5.16^{b}	6.33^{b}	6.09^{b}	2.71^{c}	8.19^{a}	0.94^{d}
	GP	90^{a}	90^{a}	94^{a}	42^{d}	54^{c}	69^{b}	96 ^{a}	33.1^{d}
A. etbaica	GMT (days)	3.44^{b}	3.04^{ab}	2.67^{a}	5.02^{c}	3.94^{b}	2.91^{ab}	4.06^{bc}	6.79^{d}
	GI	7.24^{b}	7.95^{b}	10.4^{a}	2.57^{d}	3.92^{c}	7.32b	8.24^{b}	1.22^{e}
	GP	83.0^{bc}	78.00^{c}	95.0^{a}	60.0^{d}	52.00^{d}	91.0^{ab}	930^{ab}	24.0^{e}
A. gerrardii	GMT (days)	6.87^{cd}	6.13^{c}	4.74^{a}	6.06^{c}	5.16b^{c}	4.91^{b}	4.13^{a}	7.43^{d}
	GI	3.28^{c}	3.99 ^{c}	6.53^{a}	2.72^{d}	2.92^{d}	5.53^{b}	6.28^{ab}	0.77^{e}
	GP	42.4^{cd}	49.0^{bc}	92. ^{a}	60.0^{b}	60.0^{b}	90.0^{a}	87.5^{a}	30.4^{d}
A. origena	GMT (days)	7.35^{b}	7.23^{b}	5.44^{a}	6.70^{b}	6.90^{b}	4.89^{a}	5.33^{a}	9.14^{c}
	GI	3.28^{cd}	3.99^{c}	6.5 ^{a}	2.72^{d}	2.93^{d}	5.53^{b}	6.29^{ab}	0.77^{e}

GP = Germination (%); GI = germination index; GMT = germination mean time (days). A = Acid; H = hot water; S = scarification; C = control. Means followed by the same letter in a row are not significantly different at P < 0.05.

least GP (98, 94, 88, 97 and 31.55%, respectively) (Table 3). Regarding GMT, all treatments recorded significantly (P < 0.05) less time for germination as compared to the control (Table 3). Scarified seeds recorded the highest GI (8.19) followed by acid treatments and hot water and the least GI occurred in control seeds (0.94) (Table 3). Similarly, GP for *A. etbaica* was significantly (P < 0.05) higher in scarified seeds (96%), seeds treated with concentrated sulphuric acid (90 to 94%) and least in seeds immersed for 2 min in hot water (42%) and the control seeds (33.14%), although there was no significant difference between the latter (Table 3).

The results for *A. gerrardii* are summarized in Table 3. Maximum GP (83.0 to 95%) was recorded in scarified seeds, acid treated seeds for 5 and 15 min and seeds immersed in hot water for 6 min, whereas the control seeds germinated by only 24.0%. Scarified seeds and hot water treated seeds (6 min) showed the least GMT (4.13 and 4.91 days), whereas the maximum GMT was recorded for control seeds (7.43 days). GI was significantly (P < 0.05) much higher in acid treated seeds (15 min) and scarified seeds (6.53 and 6.28) followed by the rest of the treatments, nevertheless the least GI was recorded in the control seeds (0.77).

Moreover, for *A. origena*, maximum GP occurred in seeds treated with acid for 15 min (92.0%), hot water for 6 min (90.0%) and scarified seeds (87.5%), although there were no significant differences between these treatments (Table 3). Hot water treatments (2 and 4 min) gave significantly (P < 0.05) more germinated seeds (60.0%) as compared to acid treated seeds (5 and 10 min; 42.4 and 49.0%, respectively). Control and acid treated seeds (5 min) recorded the least GP (30.4 and 42.4%, respectively). GI was maximum in scarified seeds and 6 min hot water treated seeds (6.29 and 5.53, respectively), while the least GI occurred in the control seeds (0.77) (Table 3).

Effect of seed treatment on germination (Al Baha region)

In this region, seed pretreatment significantly (P < 0.0001) affected germination of all tree seed species (Table 4). For *A. asak*, all types of seed treatments gave significantly (P < 0.05) maximum GP (86.0 to 97.0%) as compared to the control (31.4%) (Table 5). Similarly, GMT was significantly (P < 0.05) less in all treatments (2.43 to 3.49 days) than in the control seeds (5.56 days). Maximum GI was recorded in scarified and 15 min acid treated seeds (12.9 and 12.89, respectively), while the GI for the rest of the treatments (4.24 to 9.29) was significantly (P < 0.05) higher as compared to the control (1.56).

For *A. ehrenbergiana*, seeds immersed in acid for 5 min germinated by 100%, followed by hot water soaking for 4 min, 10 min acid treated and scarified seeds (92.0, 91.0 and 90.0%, respectively) (Table 5). The GP of all treated seeds was much higher than that of the control seeds (36.6%) with the exception of 15 min acid immersed seeds (36.0%) (Table 5). The GMT was least in 10 min acid immersed seeds (2.93), although treatments recorded significantly (P <0.05) much less GMT of 3.35 to 4.69 days as compared to the control (7.95 days). Maximum GI occurred in 10 min acid immersed seeds (8.33). The GI was significantly (P <0.05) more in all

Table 4. Effect of seed pretreatment on germination of the five *Acacia* spp. (Al Baha region) (ANOVA).

Species	Parameter	Source	DF	SS	MS	F value	P	R² (%)
A. asak	GP	Model	7	20132.56	2876.08	36.87	< 0.0001	90.85
		Error	27	2028.38	78.01			
	GMT		7	36.37	5.19	5.04	< 0.0001	57.58
			27	26.78	1.03			
	GI		7	353.84	50.55	74.95	< 0.0001	95.28
			27	17.53	0.67			
A. ehrenbergiana	GP		7	23973.25	3424.75	23.46	< 0.0001	85.87
			27	3941.71	145.98			
	GMT		7	93.9	13.41	12.54	< 0.0001	76.47
			27	28.89	1.07			
	GI		7	177.97	25.42	27.01	< 0.0001	87.50
			27	25.38	0.94			
A. etbaica	GP		7	17111.88	2444.55	25.67	< 0.0001	86.93
			27	2570.85	95.21			
	GMT		7	52.66	7.52	5.83	< 0.0001	60.18
			27	34.84	1.29			
	GI		7	196.07	28.01			
			27	20.15	0.74	37.53	< 0.0001	90.67
			27	641.34	23.75			
A. gerrardii	GP		7	19958.74	2851.24	31.98	< 0.0001	89.23
			27	2407.42	89.16			
	GMT		7	92.56	13.22	12.18	< 0.0001	75.95
			27	29.3	1.08			
	GI		7	196.08	28.01			
			27	20.15	0.74	37.53	< 0.0001	90.67
			27	344.15	12.74			
A. origena	GP		7	15978.97	2282.71	16.32	< 0.0001	80.86
			27	3776	139.85			
	GMT		7	94.19	13.45	8.15	< 0.0001	67.86
			27	44.59	1.65			
	GI		7	59.69	8.52	20.49	< 0.0001	84.15
			27	11.23	0.41			

GP= Germination (%); GI= germination index; GMT= germination mean time (days).

other treatments (2.93 to 8.33) as compared to the control (1.15) (Table 5).

Results for *A. etbaica* indicated that maximum GP occurred in scarified and 15 min acid immersed seeds (83.0 and 80.0%, respectively) (Table 5). Other treatments recorded significant ($P < 0.05$) GP (40.0 to 63.0%) than the control (17.14%). Also, all treated seeds recorded significantly ($P < 0.05$) much less GMT (2.58 to 4.4.75 days) as compared to the control (6.53 days). The GMT was significantly ($P < 0.05$) less in 15 min acid immersed seeds (2.58 days) as compared to the remaining treatments including the control. All treatments produced significantly (($P < 0.05$) higher GI (2.41 to 9.00) as compared to the control (0.61) (Table 5). Seeds immersed in acid for 15 min recorded the maximum GI (9.0).

For *A. gerrardi*, the GP was significantly ($P < 0.05$) more in all treated seeds (34.0 to 87.0%) compared to the control (22.28%) (Table 5). The maximum GP occurred in scarified and 15 min acid immersed seeds (87.0 and 80.0%). Generally, the treated seeds recorded significantly ($P < 0.05$) much less GMT (4.7 to 7.12 days) in comparison to the control (9.35 days). The least GMT occurred in scarified, then in 4 and 6 min hot water

Table 5. Effect of seed pretreatment on mean germination parameters of 5 *Acacia* (Al Baha region).

Species	Parameter	Seed pretreatment							
		A5	A10	A15	H2	H4	H6	S	C
A. asak	GP	93.0^{a}	97.0^{a}	93.3^{a}	92.0^{a}	86.0^{a}	89.0^{a}	88.0^{a}	31.4^{b}
	GMT (days)	3.09^{a}	2.84^{a}	2.43^{a}	3.49^{a}	3.39^{a}	3.28^{a}	3.00^{a}	5.56^{b}
	GI	8.16^{b}	9.29^{b}	12.89^{a}	3.71^{d}	4.24^{d}	7.12^{c}	12.9^{a}	1.56^{e}
A. ehrenbergiana	GP	100^{a}	91.0^{ab}	36.0^{c}	87.0^{b}	92.0^{ab}	80.0^{b}	$90.^{ab}$	36.6^{c}
	GMT (days)	4.56^{b}	2.93^{a}	3.35^{ab}	4.56^{b}	4.44^{b}	4.25^{ab}	4.69^{b}	7.95^{c}
	GI	6.63^{b}	8.33^{a}	2.93^{c}	5.48^{b}	5.55^{b}	5.39^{b}	5.53^{b}	1.15^{d}
A. etbaica	GP	63.0^{b}	45.0^{c}	80.0^{a}	46.0^{c}	40.0^{c}	60.0^{bc}	83.0^{a}	17.14^{d}
	GMT (days)	4.45^{b}	3.18^{ab}	2.58^{a}	5.33^{bc}	4.76^{b}	4.56^{b}	4.75^{b}	6.53^{c}
	GI	3.72^{b}	3.69^{bc}	9.00^{a}	2.46^{c}	2.41^{c}	3.72^{b}	4.86^{b}	0.61^{d}
A. gerrardii	GP%	34.0^{cd}	67.0^{b}	80.0^{ab}	45.0^{c}	71.0^{b}	79.0^{ab}	87.0^{a}	22.28^{d}
	GMT (days)	7.12^{b}	7.35^{b}	5.29^{ab}	6.28^{b}	5.47^{ab}	5.05^{ab}	4.70^{a}	9.35^{c}
	GI	3.72^{b}	$3.69b^{c}$	9.00^{a}	2.46^{c}	2.42^{c}	3.72^{b}	4.86^{b}	0.62^{d}
A. origena	GP	58.0^{b}	58.0^{b}	74.0^{ab}	38.0^{c}	$42.0b^{c}$	56.0^{b}	82^{a}	16.0^{d}
	GMT (days)	7.47^{b}	6.42^{ab}	5.84^{ab}	7.43^{b}	6.80^{ab}	5.19^{a}	5.70^{ab}	10.08^{c}
	GI	2.08^{bcd}	2.59^{bc}	4.02^{a}	1.32^{d}	1.66^{cd}	3.12^{ab}	3.95^{a}	0.28^{e}

GP= Germination (%); GI= germination index; GMT= germination mean time (days). A = Acid; H = hot water; S = scarification; C = control. Means followed by the same letter in a row are not significantly different at P < 0.05.

immersed seeds (4.70, 5.47 and 5.05 days, respectively) (Table 5). The GI in all treated seeds was significantly (P < 0.05) more (2.42 to 9.0) than that in the control seeds (0.62) (Table 5). However, the maximum GI occurred in 15 min acid immersed seeds (9.0).

Finally, for *A. origena*, the GP of all treated seeds was significantly (P < 0.05) higher (38.0 to 82.0%) than that in the control seeds (16.0%) (Table 5). Scarified and 15 min acid immersed seeds had the maximum overall GP (82.0 and 74.0%, respectively) (Table 5).

Effect of seed treatment on germination (Al Madinah region)

Results on *A. ehrenbergiana* collected from Al Madinah region indicate that seed treatment significantly (P < 0.0001) affected germination of seeds (Table 6). GP was 69 to 82.0% in treated seeds and 43.43% in the control. Scarified seeds had the highest GP (82.0%), while acid and hot water treated seeds recorded more or less similar GP. The recorded GMT was least in all acid and 6 min hot water immersed seeds (2.93 to 3.49 days), whereas it was 7.4 days in the control seeds. The GI was also more in 10 and 15 min acid immersed seeds (2.87 and 2.93) and significantly (P < 0.05) less in the control seeds (1.52).

Effect of geographic source on germination

For *A. asak*, geographic source of seeds significantly (P < 0.0001) affected GP of seeds immersed in hot water. The GP for seeds collected from Al Baha region was much higher (66.0%) than those from Aseer region (89%) (Table 7). In contrast, scarified seeds obtained from Aseer region recorded significantly (P < 0.01) more GP (96.0%) than those collected from Al Baha Region (88.0%) (Table 7). More also, the GMT was significantly (P < 0.01) less for seeds from Al Baha (3.4 days) than those from Aseer region (4.1 days) in seeds immersed in hot water, and the trend was similar for scarified seeds (Table 7). Similarly, GI was significantly (P < 0.0001) affected by the geographic source in seeds immersed in hot water and scarified seeds (P < 0.001) (Table 7). However, germination was not affected by seed source in acid immersed and control seeds.

Furthermore, *A. etbaica* GP was significantly affected by seed source in acid immersed, scarified and control seeds (P < 0.0001, P < 0.05 and P < 0.05, respectively) (Table 7). However, GP was not affected by seed source in hot water immersed seeds. The GMT was significantly (P < 0.01, P < 0.05) affected by seed source in seeds immersed in hot water and scarified seeds (Table 7). The GMT was not affected by seed source in acid immersed and control seeds. Seed source also significantly (P <

Table 6. Effect of seed pretreatment on germination of *A. ehrenbergiana* (Al Madinah region) (ANOVA).

Parameter	Source	DF	SS	MS	F value	*P*	R^2 (%)
GP	Model	7	5982.86	854.69	13.31	< 0.0001	77.53
	Error	27	1733.71	64.21			
GMT (days)	Model	7	88.76	12.68	22.04	< 0.0001	85.11
	Error	27	15.51	0.58			
GI	Model	7	176.86	25.26	23.87	< 0.0001	86.08
	Error	27					

GP= Germination (%); GI= germination index; GMT= germination mean time (days).

Table 7. Effect of seed pretreatment on germination of *A. ehrenbergiana* (Al Madinah region).

Parameter	Seed pretreatment							
	A5	A10	A15	H2	H4	H6	S	C
GP	74.0^{ab}	74.00^{ab}	72.00^{ab}	79.00^{ab}	69.00^{b}	74.00^{ab}	82.00^{a}	43.43^{c}
GMT (days)	3..49^{ab}	2.87^{a}	2.93^{a}	4.27^{b}	4.09^{b}	3.45^{ab}	4.75^{b}	7.40^{c}
GI	6.34 ^{b}	8.83^{a}	7.41^{ab}	5.11b^{c}	4.75^{c}	5.88b^{c}	4.56^{c}	1.52^{d}

GP= Germination (%); GI= germination index; GMT= germination mean time (days). A = Acid; H = hot water; S = scarification; C = control. Means followed by the same letter in a row are not significantly different at P < 0.05.

0.001, > 0.01, < 0.05, < 0.05) affected GI in all treatments, respectively (Table 7). Also, for *A. gerrardii*, seed source significantly affected GP (P < 0.001) and GI (P < 0.01) in acid treated seeds, although no significant difference was recorded for the remaining treatments (Table 7). In addition, GMT was not affected by the seed source in all the treatments.

More also, for *A. origena* in hot water immersed and scarified seeds, seed source significantly (P < 0.001 and < 0.01, respectively) affected GP, whereas no significant differences were recorded for other treatments (Table 7). GMT was significantly (P < 0.01) affected by seed source only in scarified seeds. GMT for the other treated seeds was not affected. Also the seed source had a significant (P <0.05 and < 0.001) effect on GI in hot water immersed and scarified seeds (Table 7).

Finally, for *A. ehrenbergiana*, scarified seed treatment was the only one where seed source significantly (P < 0.001) affected GP (Table 7). Other seed treatments showed no significant (P > 0.05) effect of seed source on GP. Significant (P < 0.05, < 0.05, > 0.0001) effects of seed source on GMT were recorded in acid and hot water immersed and scarified seeds, whereas in the control seeds, the effect was not significant (P > 0.05) (Table 7). The GI was significantly affected by seed source in acid immersed and scarified seeds (P < 0.05, < 0.0001, respectively), whereas no significant (P > 0.05) effect was recorded for other seed treatments. Seed treatment and geographic source therefore interacted and significantly (P < 0.0001) affected GP, GMT and GI (Table 8).

DISCUSSION

The hard seed coat of many arid zone plants has evolved to overcome unfavorable environmental conditions such as heat by direct sunlight, digestive enzymes of animals, exceptionally severe drought and mechanical damage (Freas and Kemp, 1983; Washitani and Masuda, 1990; Fenner, 1991; Meyer et al., 1991; Silvertown, 1999). This seed coat hardiness is an important factor that affects the germination pattern (Lodge and Whalley, 2002); without breaking this dormancy, it is not possible to obtain the required quantities of seedlings. Seed dormancy has several advantages to plants (Tao 2000) as it enriches the soil seed bank with hard seeds, provides germination over a period of time whenever environmental conditions are suitable for seedling growth and survival (Morgan, 1998; Wang et al., 1998). Therefore, breaking the seed dormancy by softening the seed testa to allow water imbibition is crucial for any afforestation and deforestation programmes.

In this study, all seed treatments significantly affected various germination parameters (GP, GMT and GI) in all the tree seed species studied. Generally, seeds from four *Acacia* species germinated better and faster after scarification (abrasion and acid treated). Germination behavior of *A. ehrenbergiana* was different compared to other species. For instance, increasing the time of immersion in acid decreased the GP in seeds collected from both Aseer and Al Baha regions. However, this response did not occur in seeds collected from Al Madinah where

Table 8. Interaction of seed pretreatment and seed source (ANOVA).

Species	Parameter	Source	DF	SS	MS	F value	*P*	R² (%)
A. asak	GP	Model	15	37037.94	2469.19	22.22	< 0.0001	86.05
		Error	54	6001.14	111.13			
	GMT (days)		15	98.29	6.55	7.71	< 0.0001	68.16
			54	45.91	0.85			
	GI		15	981.85	64.12	76.22	< 0.0001	95.49
			54	45.43	0.84			
A. ehrenbergiana	GP		23	52.91	2300.63	18.87	< 0.0001	84.27
			81	9873.14	121.89			
	GMT (days)		23	265.5	11.54	14.77	< 0.0001	80.75
			81	63.31	0.78			
	GI		23	539.51	23.45	23.84	< 0.0001	87.13
			81	79.69	0.98			
A. etbaica	GP		15	43402.63	2893.51	32.06	< 0.0001	89.90
			54	4873.71	90.25			
	GMT (days)		15	130	8.67	9.49	< 0.0001	72.49
			54	49.32	0.91			
	GI		15	612.86	40.86	49.26	< 0.0001	93.19
			54	44.78	0.63			
A. gerrardii	GP		15	45556.91	3037.13	39.66	< 0.0001	91.67
			54	4135.42	76.58			
	GMT (days)		15	156.21	10.14	10.85	< 0.0001	75.07
			54	51.84	0.96			
	GI		15	266.94	17.79	48.91	< 0.0001	93.14
			54	19.64	0.36			
A. origena	GP		15	38532.34	2568.82	19.3	< 0.0001	84.27
			54	7187.42	133.1			
	GMT (days)		15	192.68	12.84	10.24	< 0.0001	73.99
			54	67.73	1.25			
	GI		15	198.81	13.25	28.67	< 0.0001	88.84
			54	24.96	0.46			

GP= Germination (%); GI= germination index; GMT= germination mean time (days).

GP was more or less similar at all time intervals of immersion in acid. In this species, the highest germination of seeds collected from both Aseer and Al Baha regions, occurred in 5 min acid immersed, scarified and 4 min immersed seeds in hot water. In contrast, *A. origena* germinated better with increasing time of immersion in acid and hot water. More also, *A. origena* recorded comparatively the least GI and GMT. The response of *A. ehrenbergiana* seeds to presowing treatments was similar in seeds collected from both Aseer and Al Baha regions and different from those collected from Al Madinah. This might be attributed to seed coat thickness and genetic differences (Fischer et al., 2009). These results therefore indicate that geographic source might play an important role in the response of seeds to presowing treatments. Generally, seed source signifi-cantly affected most germination parameters of all the tree seed species tested.

However, unlike seed treatment, some germination parameters were not influenced by seed source. Seed treatment and source interacted and significantly affected all germination parameters of all the tree seed species investigated. These results are in line with the findings of several investigators. Habitat characteristics were reported to have significant effects on seeds (Sheridan and Karowe, 2000; Kollman and Pflugshaup, 2001; Henriquez, 2004; Munzbergova and Plackova, 2010). Germination of eastern red cedar seeds was significantly affected by geographic seed sources which interacted with seed treatment (David et al., 1985). Deborah et al. (2002) reported that germination of lodge pole pine (*Pinus contorta* var. *latifolia*) seeds in northeastern Utah was the best from large mineral microsites as compared to sites with less minerals after harvesting. Germination of *Echinacea purpurea* and *E. pallida* seeds from a commercial organic seed source was also reported to be more than seeds from a public germplasm source (Fredy et al., 2005). In contrast, a study of the effect of seed source on germination of seeds of *Chukrasia velutina* showed that seed source alone did not affect germination (Wasuwanich and Boonarutee, 2000). The effect of seed source on germination has been demonstrated as the environmental effect on seed production. Several studies have reported that quantitative as well as qualitative production of pollen is greatly affected by the prevailing environmental conditions which may affect the ability of the mother plant to sire seeds (Young and Stanton, 1990; Delph et al., 1997; Aizen and Raffaele, 1998; Lehtilä and Strauss, 1999).

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