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GERMINATION OF IMPORTANT EAST AFRICAN MOUNTAIN FOREST TREES.

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ABSTRACT

The germination ecology of 25 tree species of the montane forests of Mount Kenya (Kenya) was studied. Five different germination strategies could be observed under similar ecological conditions. Pioneer species often required mechanical scarification before germinating, but did not react to different light conditions. Many species germinated without scarification, but were strongly influenced by the duration of seed storage. An equally high number of species positively reacted to bright illumination. Primary forest species mainly germinated under low illumination or dark conditions and showed a very short seed viability. The storage temperature did not influence viability, whereas the maturity of the seeds collected had a considerable influence on the germination success.

INTRODUCTION

The forests of Kenya, and of Mount Kenya in particular, have been subjected to heavy logging for decades. Moreover, due to selective logging, they also have undergone significant qualitative changes. Kenya originally had about 80,000 km^2 of natural forest cover (15% of the country) (Myers, 1979). Today, even including plantations of exotic species, only a quarter of this area merits the term forest. Two hundred years ago, still 40,000 km^2 of forests were left in Kenya. A present trend for deforestation is given by Barnes (1990) who estimated a loss of 6,900 km^2 for indigenous Kenyan forests in 1980. Although private tree planting of exotic species has reduced the fuelwood deficit considerably (Holmgren *et al.*, 1994), the destruction of the natural forests has increased drastically during the last decades. Currently, Kenya has an annual deforestation rate of 1.5%, which is in part driven by a human population growth rate of 3.8%. If current rates of forest clearing continue, no natural forest will remain by the year 2040 (Barnes, 1990).

Despite these facts, very few studies have been carried out on the germination ecology of indigenous forest tree species in Eastern Africa (Albrecht, 1993; Braun *et al.*, 1993; Negash, 1992, 1993). Therefore, the presented work is important for the understanding of the germination ecology of many important tree species of the whole East African montane forest area.

MATERIALS AND METHODS

Seeds of 25 important montane forest tree species were obtained from KEFRI (Kenya Forest Research Institute) or were collected from Mount Kenya Forest Reserve. All seeds were stored a maximum of two weeks at 20°C after collection, and were soaked in cold water for 24 h before the experiment. One set of seeds received no further treatment, whereas for a second set, all hard seed coats were removed or scarified, either by cracking the seed coat, or by using sandpaper. For each treatment and each species, 200 seeds were germinated under each of the following conditions:

Germination on sterile filter paper in standard petri dishes (7 cm diameter) in the Botany Department Laboratory of the University of Nairobi and the experimental greenhouse of the University of Tuebingen, both under the natural light regime and in the dark, at 20°C and 70% humidity.

Germination in standard 1000 ml polyethylene germination bags in natural forest soil in the nursery of the Botany Department of the University of Nairobi, under the climatic conditions present during the study period.

All germination experiments were run for 120 days with daily watering, under equal conditions and the germination success, as well as the germination duration, were noted. Six months and two years after collection another 100 seeds of each species were used to investigate the possible effect of storage. All seeds were stored dry in airtight plastic containers at 20°C. Only the seeds of *Podocarpus latifolius* were stored in sterilized, moist sawdust. These seeds were germinated in standard germination bowls on a commercially available soil mixture in the experimental greenhouse of the University of Bayreuth at 20°C, 70% humidity, under the most favourable light and scarification conditions for each species, indicated by the first set of germination experiments. An overview on the germination of all investigated species is given in table 1.

RESULTS

Albizzia gummifera had only 34% of germinating success (46% when kept in the dark). If scarified (cracking of seed coat), 56% of the seeds germinated within 10 days and a maximum of 76% germination success was reached (figure 1). After 6 months and 2 years storage, the amount of germinating seeds after scarification even increased slightly to 86 and 94% respectively, and remained nearly constant for unscarified seeds. *Harungana madagascariensis* reacted in a similar way. This species did not germinate at all if the fleshy mesocarp was not crushed and at least partly removed. After scarification, the germination rate reached 80% (60% and 36% after storage). This suggests that *Harungana* fruits are probably eaten by animals, which leaves the seeds undamaged, but increases the germination rate.

Forty five percent of the seeds of *Croton megalocarpus* germinated within the first 20 days and gradually approached an overall level of 76% germination success in the light. In darkness germination success was only 46%, emphasizing the ecological function of *Croton* as a pioneer species. The removal of the hard seed coat led to a 76% germination within 10 days,

Table 1. An overview of the germination of all investigated species.

Time (days)		10	20	30	40	50	60	70	80	90
n = 200 (for storage experiments n = 100)										
SPECIES	Treatment									
Albizzia gummifera	light, unscarified	8	12	18	22	28	32	32	34	34
	light, scarified	56	60	64	66	70	72	72	74	76
	dark, scarified	8	10	16	20	20	20	26	28	46
	light, unscarified, 6 months storage	6	10	16	22	32	40	44	44	50
	light, scarified, 6 months storage	46	68	78	86	86	86	86	86	86
	light, unscarified, 2 years storage	14	18	30	36	42	42	48	50	50
	light, scarified, 2 years storage	58	72	88	94	94	94	94	94	94
Aningeria adolfi-friederici	light, unscarified	2	8	38	56	66	70	72	72	74
	light, scarified	0	4	30	48	60	66	70	70	70
Calodendrum capense	light, unscarified	0	10	46	58	60	68	72	72	72
	light, scarified	2	12	40	56	62	66	72	74	74
	dark, unscarified	0	0	10	56	64	66	68	70	70
	light, unscarified, 6 months storage	0	0	6	46	60	64	68	68	68
	light, unscarified, 2 years storage	0	0	0	0	0	0	0	0	0
Cordia africana	light, unscarified	2	6	28	42	54	58	60	62	62
	light, scarified	0	2	22	40	52	58	62	62	62
	dark, unscarified	0	0	0	8	12	16	16	16	16
	light, unscarified, 6 months storage	0	4	10	48	52	52	52	52	52
	light, unscarified, 2 years storage	0	0	6	10	10	10	10	10	10
Croton macrostachyus	light, unscarified	2	10	22	24	30	30	32	34	34
	light, scarified	0	8	24	26	32	32	34	34	34
	dark, unscarified	0	0	0	4	4	6	8	10	10
	light, unscarified, 6 months storage	0	2	24	24	24	24	24	24	24
	light, unscarified, 2 years storage	0	0	0	0	0	0	0	0	0
Croton megalocarpus	light, unscarified	30	46	62	70	72	72	74	74	76
	light, scarified	72	74	74	76	78	80	82	86	86
	dark, scarified	68	72	74	80	80	80	80	80	80
	light, unscarified, 6 months storage	6	20	20	20	20	20	20	20	20
	light, scarified, 6 months storage	26	36	36	36	36	36	36	36	36
	light, unscarified, 2 years storage	0	0	0	0	0	0	0	0	0
	light, scarified, 2 years storage	0	0	0	0	0	0	0	0	0
Diospyros abyssinica	light, unscarified	0	12	16	18	20	22	22	24	26
	light, scarified	6	10	18	20	22	26	26	28	28
	dark, unscarified	0	0	8	8	8	8	8	8	8
	light, unscarified, 6 months storage	0	0	4	6	8	8	8	8	8
	light, unscarified, 2 years storage	0	0	0	0	0	0	0	0	0
Dombeya goetzii	light, unscarified	6	10	26	28	32	36	40	40	42
	light, scarified	22	28	32	36	38	40	40	40	40
	dark, unscarified	4	6	10	10	14	18	18	18	18
	light, unscarified, 6 months storage	2	4	4	8	10	10	10	10	10
	light, scarified, 6 months storage	0	2	6	6	6	6	6	6	6
	light, unscarified, 2 years storage	4	6	8	8	8	8	8	8	8
	light, scarified, 2 years storage	0	6	6	6	6	6	6	6	6
Ehretia cymosa	light, unscarified	2	12	14	22	40	48	52	58	60
	light, scarified	4	18	30	44	48	58	62	62	62
	dark, unscarified	0	0	0	0	0	0	0	0	0
	light, unscarified, 6 months storage	0	0	0	2	4	8	8	8	8
	light, unscarified, 2 years storage	0	0	0	0	0	0	0	0	0
Hagenia abyssinica	light, unscarified	10	64	86	90	90	90	90	90	90
	dark, unscarified	8	56	80	90	92	92	92	92	92
	light, unscarified, 6 months storage	6	10	10	10	10	10	10	10	10
	light, unscarified, 2 years storage	0	0	0	0	0	0	0	0	0

Time (days)		10	20	30	40	50	60	70	80	90
Harungana madagascariensis	light, unscarified	0	0	0	0	0	0	0	0	0
	light, scarified	40	60	84	86	86	86	86	86	86
	dark, scarified	0	0	0	0	0	0	0	0	0
	light, scarified, 6 months storage	0	0	0	0	0	0	0	0	0
	light, scarified, 2 years storage	0	0	0	0	0	0	0	0	0
Juniperus procera	light, unscarified	0	0	0	0	0	0	0	0	0
	light, scarified	6	8	24	54	58	60	64	66	68
	dark, scarified	0	0	2	2	4	4	8	10	10
	light, scarified, 6 months storage	0	0	10	36	36	36	36	36	36
	light, scarified, 2 years storage	0	0	8	58	66	78	86	88	88
Macaranga kilimandscharica	light, unscarified	6	18	38	64	72	80	80	82	82
	light, scarified	8	22	40	68	76	82	82	82	84
	dark, unscarified	0	10	14	14	14	14	14	14	14
Markhamia lutea	light, unscarified	70	86	88	88	88	88	88	88	88
	light, scarified	72	88	88	88	88	88	88	88	88
	dark, unscarified	66	80	88	88	88	88	88	88	88
	light, unscarified, 6 months storage	10	30	52	52	52	52	52	52	52
	light, unscarified, 2 years storage	4	4	4	4	4	4	4	4	4
Newtonia buchananii	No germination with any treatment									
Neoboutonia macrocalyx	light, unscarified	4	20	34	52	68	68	70	70	70
	light, scarified	6	26	44	60	70	70	70	70	70
	dark, unscarified	0	6	10	10	10	10	10	10	10
Ochna insculpta	light, unscarified	0	6	14	18	20	24	24	24	24
	light, scarified	8	16	22	24	24	24	24	24	24
Ocotea usambarensis	No germination with any treatment									
Podocarpus falcatus	2% germination initially, no germination after storage									
Podocarpus latifolius	light, unscarified	26	40	44	58	62	68	70	72	76
	dark, unscarified	2	36	80	84	88	88	88	88	88
	dark, unscarified, 6 months storage	0	2	36	38	40	48	50	50	50
	dark, unscarified, 2 years storage	0	0	0	0	0	0	0	0	0
Polyscias fulva	light, unscarified	4	10	40	48	54	60	64	70	74
	light, scarified	6	20	50	62	70	72	76	76	76
	dark, unscarified	4	26	40	56	62	62	62	62	62
	light, scarified, 6 months storage	0	0	0	2	26	30	30	30	30
	light, scarified, 2 years storage	2	2	2	2	2	2	2	2	2
Trichilia dregeana	light, unscarified	68	78	86	86	86	86	86	86	86
	light, scarified	70	82	86	86	86	86	86	86	86
Trichocladus ellipticus	light, unscarified	0	0	6	4	4	6	10	10	10
	light, scarified	0	4	10	10	10	10	10	10	10
Vitex keniensis	light, unscarified	2	8	14	18	18	20	20	20	24
	light, scarified	4	10	18	20	20	22	26	26	26
	dark, unscarified	0	0	2	10	10	10	12	12	12
	light, unscarified, 6 months storage	0	0	2	4	6	8	8	8	8
	light, unscarified, 2 years storage	0	0	0	0	0	0	0	0	0
Zanthoxyllum gillettii	No germination with any treatment									

suggesting a positive influence of passage through the intestinal tract of animals. However, if whole and intact fruits (each containing three seeds) were placed in the germination tubes without any further treatment, only one of the seeds present germinated in all experiments. After storage of six months, only 20% of the seeds were still viable, and after two years no seeds germinated.

Calodendrum capense, *Cordia africana,* and *Croton macrostachyus* were found to germinate slowly, reaching maxima of 72, 62 and 34%, respectively (figures 2 & 5). Darkness had no influence on *Calodendrum* seeds, but reduced the germination of the other two species to 18 and 10%, respectively. In all three of these species short storage had only minor negative effects. However, after two years only seeds of *Cordia africana* still germinated (10%).

Only very few seedlings of *Hagenia abyssinica* were observed in the field, suggesting that the germination of this species must be inhibited either by dense undergrowth or by allopathic effects of mother trees, as no seed predation could be observed. The latter seems possible because even without undergrowth no seedlings were found in areas where old trees were still alive and had not been injured by fire for a long time. Under experimental conditions, *Hagenia* germinated very quickly, reaching 64% after 20 days, and a maximum of 90% after 50 days. This high success is even more astonishing as the seeds used were collected

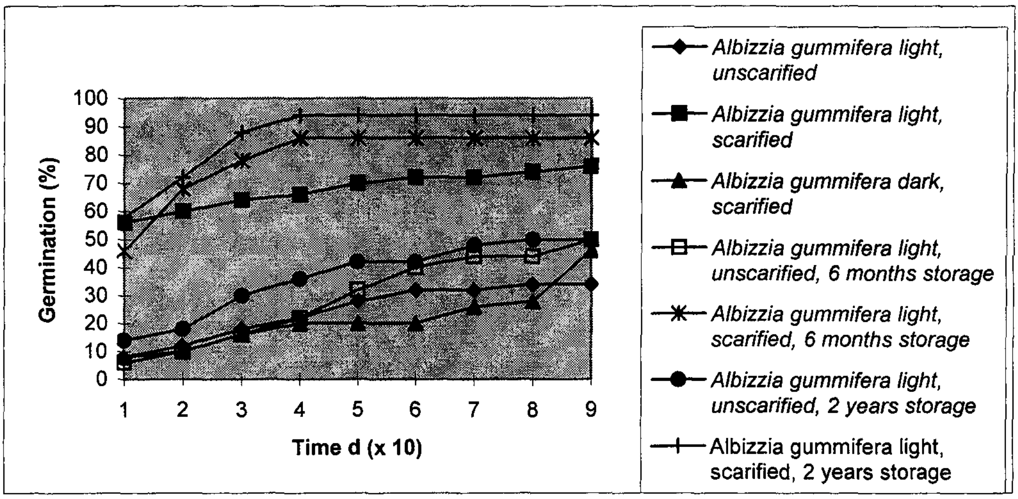

Figure 1. Germination of Albizzia gummifera

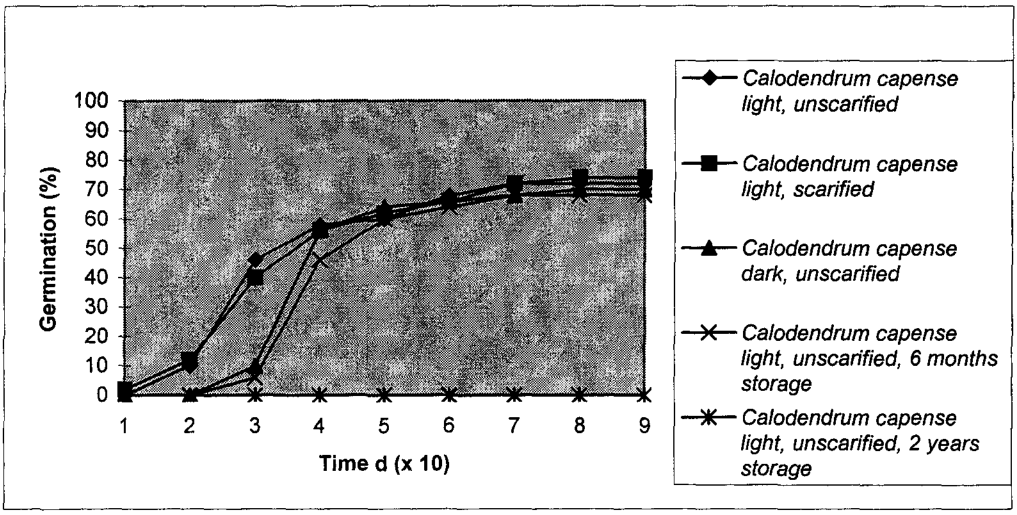

Figure 2. Germination of Calodendrum capense

randomly in the field and were used without a previous viability control. Storage lowered the germination success dramatically, with only 10% seeds germinating after six months, and no more germination after longer storage periods.

Seeds of *Juniperus procera* were sensitive to light (figure 4). Germination increased gradually, reaching a maximum of 68% under bright light as compared to 10% under dark conditions, suggesting that the species needs open places to regenerate successfully from seeds. This rate dropped to 32% after six months. Long storage seemed to have a positive effect on germination success, as after two years still 88% of the seeds used germinated in bright light.

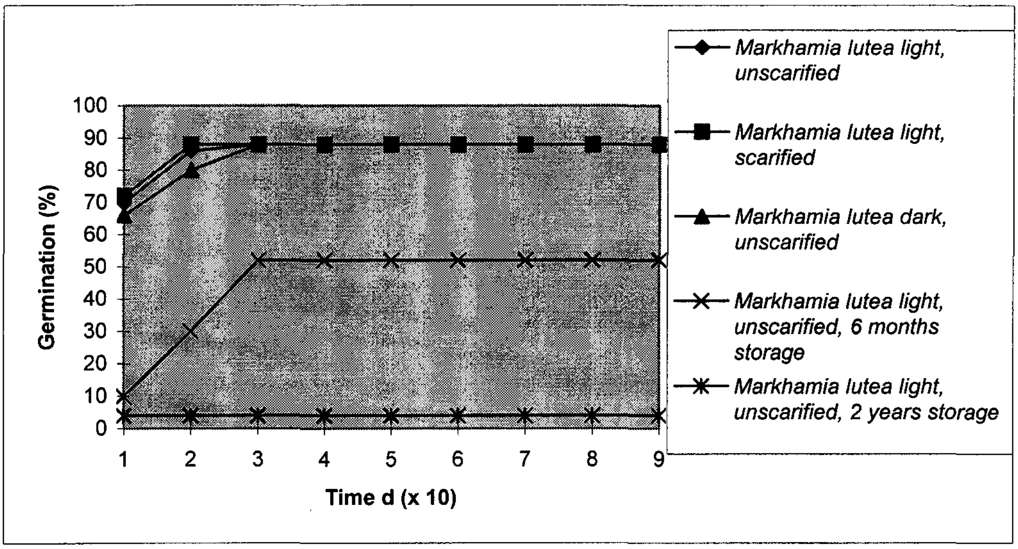

Figure 3. Germination of Markhamia lutea

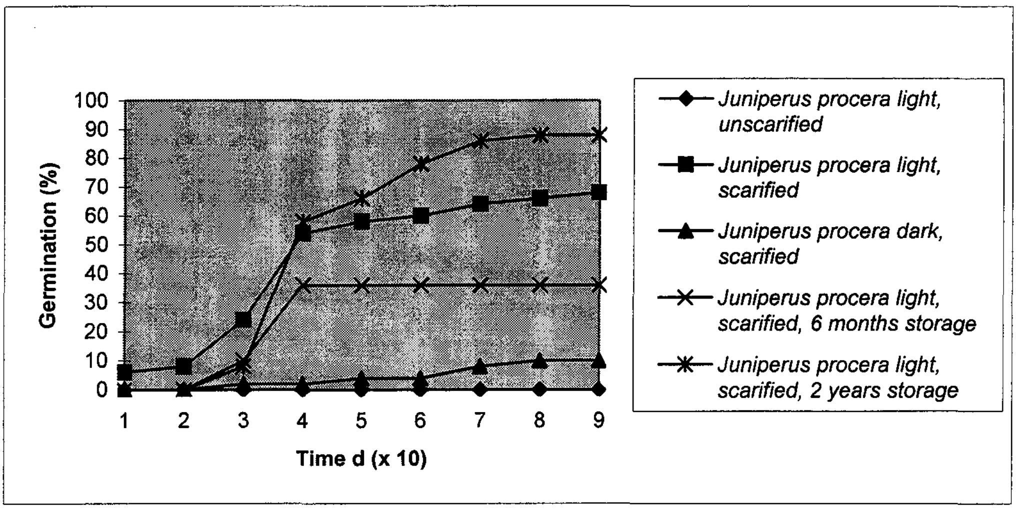

Figure 4. Germination of Juniperus procera

Macaranga kilimandscharica and *Neoboutonia macrocalyx*, both pioneer species of the submontane camphor forests, were found to germinate quickly in light, reaching a maximum of 82 and 72% germinated seeds, respectively. In the dark, germination was clearly inhibited, underlining the function of these species as fast growing, light loving secondary trees. *Aningeria adolfi-friederici*, an important primary forest species in lower montane forests, reached 76% germination, a germination level only a little lower than the previous ones. However, no data are available for the performance of this species in the dark and for the effects of storage.

Markhamia lutea, a species of the submontane primary camphor forests, was found germinating within a few days with a maximum germination of 88% under illumination as well as darkness (figure 3).

The seeds of *Trichilia dregeana*, another very fast germinating species of the camphor forests, lost their viability within a few days, a feature frequently observed with species of lowland rainforests. The high germination level (86%) seems to compensate for the short life span of the seeds.

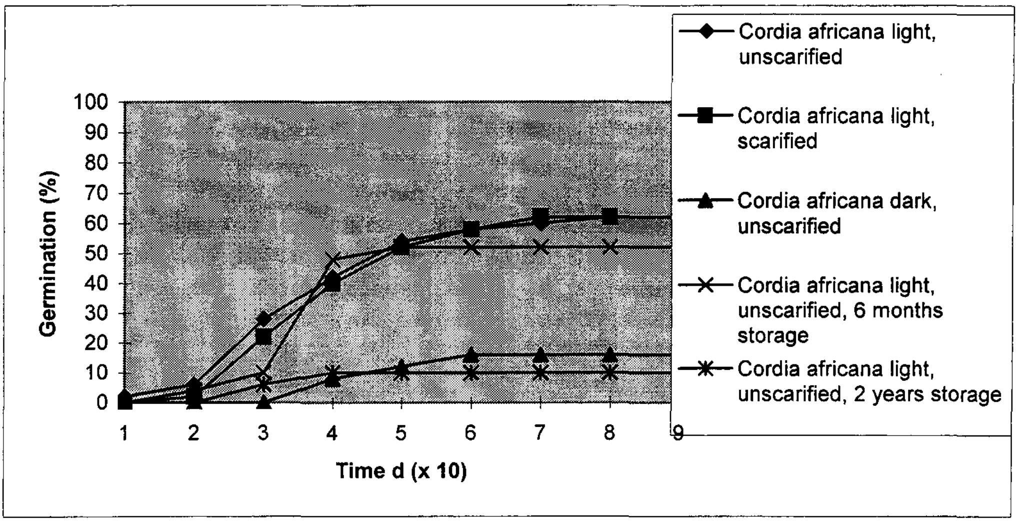

Figure 5. Germination of Cordia africana

A similar dependence on illumination was found for *Polyscias fulva* and *Ehretia cymosa*. *Polyscias fulva* had a germination success of 74% and was not influenced by the amount of light available. The latter species reached 60% germination in the light but did not germinate at all in the dark. This applies also to *Dombeya goetzii* that germinated to 18% in the dark, compared to 42% under illumination. If the seed coat was cracked, the seeds germinated with about the same success but twice as fast.

Among the species of the submontane and montane forests, *Podocarpus latifolius* germinated rapidly and reached 76% success in the light and 88% in the dark. This fits well with the fact that the species was found germinating even in the darkest forests. However, only 50% of the seeds germinated after storage, and longer storage periods led to a complete loss in germination success.

Diospyros abyssinica, *Vitex keniensis*, *Ochna insculpta* and *Trichocladus ellipticus*, all mainly found in the submontane camphor forests, germinated very slowly and reached only maximum yields of about 20%. Darkness had a negative effect, while scarification, either by removing or cracking the seed coats had no influence. In some species seed storage had a very negative influence on viability. With the exception of *Polyscias*, which still showed a germination success of 30%, all other species fell below 10% of germinating seeds.

A few species did not germinate under the experimental conditions applied, e.g. *Podocarpus falcatus*, which probably did not germinate due to its hard seed coat. However, after removing the shell, the oily seeds either started rotting or were eaten by ants. *Zanthoxyllum gillettii* and *Newtonia buchananii* also showed no germination. The first species probably failed due to an inhibitor in the seeds, as they did not germinate even after removing the oily seed coat, the latter due to unknown reasons. Even in forests with a high percentage of *Newtonia buchananii*, only very few seedlings of this species were found.

Ocotea usambarensis, by far the most heavily exploited timber tree, also showed severe germination problems. Only very few apparently intact looking seeds were found in the field as most were already attacked by gall insects while unripe, or were eaten by birds. The few seeds collected did not germinate, suggesting that *Ocotea* seeds are unviable or only viable for a few days.

DISCUSSION

In general, the obtained germination maxima under illumination are well comparable to the data mentioned by Albrecht (1993) and Braun *et al.*, (1993). Short storage at room temperature had little or no negative effects on the viability of the seeds, whereas long-term (two year) storage typically led to a complete loss of viability. This will be important especially for local nurseries, where often no cooling facilities are available. Some species responded positive to dark conditions, leading to the highest germination success. In the case of *Zanthoxyllum gillettii* and *Podocarpus falcatus*, our germination experiment failed completely without any explanation.

Vázquez-Yanes & Orozco-Segovia (1993) discussed the occurrence of very different germination patterns in tropical forest species. A similar trend could be observed in the species tested here and five clear categories are recognised:

- SPECIES REQUIRING SCARIFICATION: *Albizzia gummifera* (figure 1), which is wind-dispersed and *Harungana madagascariensis*, dispersed by monkeys and birds, germinate badly or not at all without scarification. Both are pioneer species, but are not dispersed over a long distance, and are often found just rotting under the mother trees. This might explain the minimal effect of storage on germination success. Similarly long survival due to hard seed coats was found *e.g.*, for *Piper* spp. by Orozco-Segovia & Vâsquez-Yanes (1989), *Maesopsis eminii* (Mugasha & Msanga, 1987) and *Ochroma lagopus* (Vâsquez-Yanes, 1974).
- INDIFFERENT SPECIES: *Calodendrum capense* (figure 2) responded completely indifferent to light conditions, scarification, and short term storage. This species occurring in dry montane broad-leaved forests, germinates fast after the start of the often irregular rainy season. *Markhamia lutea* (figure 3), *Podocarpus latifolius, Polyscias fulva* and *Croton megalocarpus* also showed no correlations between germination and light conditions, but were susceptible to storage. These species grow in wet forests and produce seeds all year round. Therefore, a very long seed viability is not required, resulting in a fast drop of germination success. After six months storage maximum germination of *Markhamia lutea* dropped to 52%, and after two years to only 4% (figure

3). This matches the ecological requirements of the species, which is found in deep forest as well as in gaps.

- LIGHT DEPENDENT SPECIES: Of all trees examined, *Juniperus procera* (figure 4) was the most dependent on bright sunlight. Wimbush (1937) and Hall (1984) noted the same phenomenon. This species is always found germinating rapidly after a forest fire, forming dense stands in otherwise bare areas. This fact also explains the low viability after storage, as after a few months the open fire areas will already be colonized by a dense cover of herb species, if no germination of *Juniperus* has taken place earlier. *Juniperus* germinated only after complete removal of the oily fruit mantle, while untreated seeds did not germinate. Even if the fruits were crushed but the flesh was not completely removed, or if crushed fruits were put near clean seeds, no germination took place. This strongly suggests an inhibiting effect of a component of the fruits, corresponding well to the field observations, where plenty of fruits were found rotting under the mother trees, showing no germination at all, and thus suggesting allelopathic effects. An influence of a fungal or bacterial attack on the seeds could not be observed. In natural forests, germinating seeds were found under scarred old trees only few days after a fire had passed. This might explain the fast germination of *Juniperus* after fire, which probably destroys the allelopathic compounds and simultaneously destroys competitors for light.

  Colonizers such as *Diospyros abyssinica, Vitex keniensis, Dombeya goetzii* and *Ehretia cymosa*, although having lower germination levels, showed a similar pattern as *Juniperus*. The low germination success of *Vitex* in comparison to Albrecht (1993) is surprising. It can be assumed, that the obtained seeds were not mature at the time of collecting. Other light loving trees, in particular *Cordia africana* (figure 5) and *Croton macrostachyus*, which are found in humid forest areas, are not affected by fires, and therefore show a more gradual germination, with no influence of short seed storage.

- FAST GERMINATING PRIMARY FOREST SPECIES: A large number of species reacted positively to dark conditions, and the same time were highly susceptible to seed storage. The species concerned are all found in very humid, primary montane forests. As observed for many other primary species, *Trichilia dregeana* and *Aningeria adolfi-friederici* germinated rapidly, however, seeds lose their viability very fast. After six months storage none of the seeds germinated.

  Similar observations on the dependency for germination on light were reported by many authors. Typical pioneer species often germinate very rapidly under favourable conditions. Garwood (1989), Orozco-Segovia & Vázquez-Yanes (1989), Raich & Gong (1990), Vásquez-Yanes (1976) and Vázquez-Yanes & Orozco-Segovia (1984, 1990) found also a high dependency on bright light conditions, as they occur e.g. in treefall gaps, for many pioneer species of tropical rainforest. Nevertheless, many primary forest species were found also germinating fast (Forget, 1992; Garwood, 1989; Ng, 1980; Raich & Gong, 1990) after being dispersed on the soil surface, as long as the soil contained enough moisture (Orozco-Segovia & Vasquez-Yanes, 1990).

- NON GERMINATING SPECIES: *Ocotea usambarensis, Zanthoxyllum gillettii, Newtonia buchananii*, and *Podocarpus latifolius* did not germinate during our experiments. *Ocotea* seems to have very low and short seed viability, whereas we could not find an explanation for the germination failure of *Zanthoxyllum*. The seeds of *Newtonia buchananii* and *Podocarpus falcatus* were probably not mature at the time of collection, as Albrecht (1993) and Negash (1992) reported germination without problems, if mature seeds could be obtained.

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