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Effects of resin tapping and tree size on the purity, germination and storage behavior of *Boswellia papyrifera* (Del.) Hochst. seeds from Metema District, northwestern Ethiopia

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ABSTRACT

Boswellia papyrifera (Del.) Hochst. is one of the tree species in dry woodlands of Ethiopia that provides several goods and services. Despite its wide economic and ecological importance, its area coverage is dwindling from time to time, and its natural regeneration is hampered. Hence, long-term prospect for a sustained supply of the goods and services from the species is becoming questionable. The objectives of this study were to investigate: (i) the effect of resin tapping and tree size (DBH) on seed susceptibility to insect attack and the production of viable seeds; and (ii) seed longevity and germination ecology of the seeds of *B. papyrifera*. We collected seeds from tapped and untapped *B. papyrifera* stands at Lemlem Teraara in Metema District, northwestern Ethiopia. The result showed that both tapped and untapped stands produced comparable insect attacked seeds (tapped stands = 16.6%; untapped stands = 15.8%). Untapped trees yielded significantly ($P < 0.0001$) higher viable seeds (59%) than continuously tapped trees (49.3%), and trees with medium size (20 cm DBH) provided more viable seeds than bigger (30 cm DBH) and younger trees (10 cm DBH). Longevity of *B. papyrifera* seeds indicated significant difference in viability under three different temperature regimes (5, 15 and 21 °C), three storage periods (6, 9 and 12 months) and two tapping regimes (tapped and untapped populations). Fire that produced temperatures above 100 °C was lethal to the seeds as it caused complete loss of germinability regardless of exposure time. However, heat with temperatures less than 100 °C did not cause loss of germinability even after an hour of exposure. We also found that light conditions had no significant impact on the germination percentage. In general, viability of the seeds was affected by tapping and tree size but not by storage conditions and period, modest temperature and light conditions.

1. Introduction

The dryland woodlands in Ethiopia own diverse tree species that are known for their valuable Non-Timber Forest Products (NTFPs) of local, national and international significance. One of the well-known species in this regard is *Boswellia papyrifera* (Del.) Hochst. The species is a deciduous multipurpose tree with the potential for economic development and desertification control (Lemenih and Teketay, 2003a, 2004). It is found in the *Combretum–Terminalia* (broad-leaved) deciduous woodland and wooded grassland usually dominant on steep rocky slopes, lava flows or sandy valleys, within the altitudinal range of 950–1800 m altitude (Eshete et al., 2005).

B. papyrifera provides several goods and services such as poles, timber, fodder, nectar and gum, which is useful for traditional medicine, religious ritual and income generation. The most important product for which the species is well known is the production of frankincense or gum olibanum. For years, frankincense has been harvested from this species for several traditional and industrial purposes. Still today, frankincense is widely used as a raw material in many industries such as pharmacology, flavoring, beverage and liqueurs, cosmetics, detergents, creams and perfumery (Lemenih and Teketay, 2003a,b). Although several *Boswellia* species produce frankincense, the one from *B. papyrifera* is the most traded in the world market (FAO, 1995). Ethiopia is the leading producer and exporter of frankincense, which is obtained from *B. papyrifera* and with significant local and national economic benefits.

In addition, *B. papyrifera* is a valuable species that thrives successfully under the conditions where soil and climate do not offer other opportunities, thus, allowing marginal drylands to be

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productively and economically utilized. This behavior of successful establishment and growth of the species under harsh climatic and soil conditions make it one of the best candidates to fight desertification, rehabilitate degraded drylands and allow adaptation of communities in drylands to possible climate change (Lemenih and Teketay, 2004).

Despite the wide economic and ecological importance of *B. papyrifera*, its area coverage is dwindling from time to time, and its natural regeneration is also hampered and, hence, the long-term prospect for a sustained supply of the goods and services from the species is being dying out. Recently, several studies (e.g. Eshete, 2002; Gebrehiwot, 2003; Ogbazghi, 2001; Ogbazghi et al., 2006a,b; Rijkers et al., 2006) described that the distribution, abundance and regeneration status of the species as not promising. In fact, *B. papyrifera* species is already listed among endangered species of East Africa that need priority in conservation (Gebrehiwot et al., 2003; Marshall, 1988).

Several factors have been stated as responsible for the degradation and lack of regeneration for the species among which frequent tapping, which means wounding the *B. papyrifera* tree to cause incense production, human induced fire, overgrazing, and climatic anomalies are some of the major (Eshete et al., 2005; Gebrehiwot, 2003; Ogbazghi et al., 2006a; Rijkers et al., 2006).

Among these factors, tapping has been reported to affect sexual reproduction and natural regeneration. The fragile relationship between the extraction of wood exudates and tree regeneration in natural populations was first demonstrated quantitatively by Rijkers et al. (2006). Rijkers et al. (2006) reported that excessive tapping can be destructive as it may weaken the tree and cause carbohydrates to be spent on exudates that might otherwise have been allocated to growth and reproduction. Furthermore it was demonstrated that tapping activities for frankincense coincide with the flowering and seed production cycle of the trees resulting in limited carbohydrates availability and, therefore, cause low production of, mainly, non-viable seeds.

At the stand level, sexual reproduction decreased with increasing tapping regime irrespective of tree size, and non-tapped trees produced three times as many healthy and filled seeds as tapped trees. Hence, tapping may cause tree exhaustion and eventually decline in vitality, which may, in turn, reduce natural regeneration of the species (Rijkers et al., 2006; Rao, 2011).

The negative effect of over-tapping for wood exudates, such as premature tree death and enhanced risk of insect and fungus infections has also been demonstrated by field observation (Gebremedhin and Negash, 1999; Ogbazghi, 2001; Torquebiau, 1984; Jemal and Huntsinger, 1993; Rijkers et al., 2006). A large proportion of seeds of *B. papyrifera* (up to 25%) that reached the ground was destroyed by insects or became infected by Fungus (Gebremedhin and Negash, 1999; Ogbazghi, 2001; Ogbazghi et al., 2006a). Trees subjected to annual tapping in Eritrea produced fewer flowers, fruits and seeds than did the trees released from tapping (Ogbazghi, 2001; Ogbazghi et al., 2006a). Moreover, the seeds obtained from untapped trees exhibited the highest germination success than the trees that were subjected to annual tapping.

The above being the realities, studies on the artificial propagation and domestication of the species are very limited, and there is a general lack of information on its seed ecology/biology and propagation techniques. This is witnessed by the absence of any successful establishment of plantation of the species, and the few trial plots established failed to show significant success. For *ex situ* and *in situ* conservation and proper management of the species, it is essential to understand the biology of the seed with respect to germination and other behaviors.

We hypothesize that current traditional tapping practices of *B. papyrifera* contributes to loss of seed viability, increased susceptibility to insect attack and lower seed longevity in storage of *B. papyrifera* seeds. The objectives of this study were, therefore, to investigate: (i) the effects of resin tapping and tree size (DBH) on susceptibility of seeds to insect attack and the production of viable seeds; and (ii) longevity and germination ecology of the seeds of *B. papyrifera*. To achieve these objectives, four experiments were carried out side by side using seeds collected from one of the natural ecosystems of the species, namely Metema District, northwestern Ethiopia.

2. Materials and methods

2.1. Site description

The seeds of *B. papyrifera* used for the present study were collected from stands found at Lemlem Terara, which is located in Metema District of North Gondar Zone (NGZ) in the Amhara National Regional State (ANRS), Ethiopia (Fig. 1). Lemlem Terara is situated at about 205 km west of Gondar town, between 36°17′–36°48′ E and 12°39′–12°45′ N. The altitude of Metema ranges from 810 to 990 m. The site is one of the natural ecosystems of *B. papyrifera* where its population is found in good stock and commercial tapping of incense is widely practiced.

2.2. Seed collection

For seed collection, two *B. papyrifera* stands, one from a site subjected to continuous tapping for 8 years (1996–2004) and the other from a site that has never been tapped for incense production were selected. From each of the selected stands, five healthy trees from three different diameter (DBH) classes (10, 20 and 30 cm) were selected. Adequate fruits were collected by hand from the crowns of each selected tree in four directions (North, South, West and East) to capture possible variations in the seed characteristics. The fruits were transported to the Forestry Research Center in Addis Ababa in plastic bags where the seeds were extracted from the capsules by hand.

2.3. Effects of resin tapping and tree size on seed susceptibility to insect attack and seed quality (Experiment I)

The effect of tapping and tree size on seed quality and susceptibility to insect infestation was assessed using seeds collected from tapped and untapped trees of three DBH classes as described above. After separating the seeds from their capsules, all of the seeds from each tree were visually inspected for signs of insect attack. Presence of holes, discoloration and fungus molds on the surface were used as signs to identify insect attacks. Those seeds found with the aforementioned signs were sorted from the whole batch of seeds of individual trees. Those identified as affected seeds were counted to assess the proportion of insect affected seeds per tree.

Simultaneously, the number of seeds that were found in a kg of *B. papyrifera* seeds was also assessed by weighing randomly picked 1000 seeds, from a mixture of tapped and untapped stand seeds, in eight replications, and the weight per kg of seeds was calculated (ISTA 1993).

2.4. Effects of tapping and tree size on seed viability (Experiment II)

To investigate whether tapping and tree size affect seed viability, 100 healthy and vigorous seeds were randomly drawn from each of the three diameter classes from untapped and tapped stands for germination tests. Thus, 300 seeds each for the tapped and untapped stands were taken for the germination tests. The seeds were, then, pre-treated by soaking them in cold water for 12 h; this treatment was reported to give the best germination results for seeds of *B. papyrifera* (Rijkers et al., 2006). The seeds were

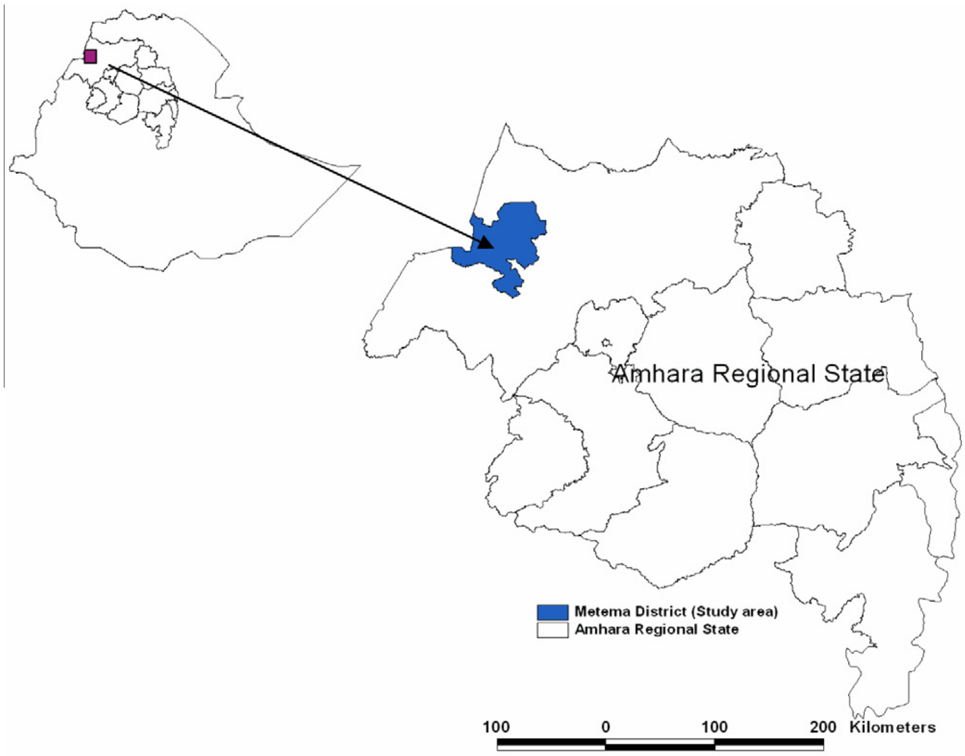

Fig. 1. Map of Ethiopia and the Amhara National Regional State showing the study area.

sub-divided into batches of 25 seeds, i.e. 4 replications of seeds (25 seeds × 4 replications × 3 diameter classes × 2 stands) each from tapped and untapped stands, and placed in 5.5 cm petri-dishes with moist filter paper. The petri-dishes were then placed in a germination cabinet (incubator) for 30 days at 20/30 °C (12/12 h) and 80% relative humidity.

The light conditions in the cabinet were 12 h light and 12 h dark. The petri-dishes were kept constantly moist with distilled water. The seeds were inspected every other day and those that germinated were counted and discarded to avoid double counting. The seeds were considered germinated when the radicle reached the size of the seed.

2.5. Effects of tapping and storage temperatures on seed longevity (Experiment III)

To study the effect of tapping and storage temperatures on the viability of *B. papyrifera* seeds (longevity), seeds from untapped and tapped trees of the three diameter classes as described above with moisture content of 5.6% right after separation from fruits, were stored in sealed plastic bags for six, nine and 12 months at 5, 15 and 21 °C. After each of the described period of storage, 100 seeds that sank after soaking in water for 12 h were drawn from trees of each diameter class and tested for germination to determine their viability. Floating seeds were excluded in this particular experiment since they represent seeds with aborted embryos (Gebremedhin and Negash, 1999). The 100 seeds were divided into four replications of 25 seeds each. The germination test was run in a similar procedure as described in Section 2.4.

2.6. Effects of fire (heat) and light on the germination of seeds (Experiment IV)

Fire has been stated as one of the factors threatening *B. papyrifera* in its natural habitat (e.g. Eshete et al., 2005). However, the effects that different intensities of fire may have on seed viability have not been assessed. Hence, the effects of different levels of temperature were investigated by exposing seeds to a range of different temperatures for different time intervals, as created by different intensities of fire, using preheated ovens. The selected temperatures were those that are likely to be reached at the soil surface or the first few centimeters below ground in savanna fires (Gashaw and Michelsen, 2002). For this experiment, seeds were soaked in cold water for ten minutes to separate the seeds that sank from floating ones, and those that sank were separated and allowed to dry at room temperature (at about 20 °C). Then, the seeds were subjected to six different temperature levels (60, 80, 100, 120, 150 and 200 °C) for 10, 20, 30 and 60 min each. For each temperature level, four replications of 25 seeds each were used. The seeds were, then, placed in moist filter paper in a petri-dish and kept in a germination cabinet in a similar procedure as described in Section 2.4.

To assess the effects of light on seed germination, seed batches collected from the untapped stands were tested for germination both under light and dark conditions. Four replications of 25 seeds each were used for the germination test. The procedure described in Section 2.5 was followed except for the seeds tested under dark conditions, which were sown in petri-dishes that were wrapped with aluminum foil immediately after sowing seeds.

2.7. Data analyses

For determination of number of seeds in a kilogram and proportion of insect attacked seeds, descriptive statistics was used. In all cases, germination percentage data were calculated as the cumulative percentage of 30 days after sowing and arcsine transformed before statistical analysis to fulfill normality. For experiments I and II, two-way ANOVA was performed where resin tapping and tree size were the main factors. For experiment III, a three-way ANOVA was performed where resin tapping, storage temperatures and storage periods were the main factors. For fire (heat) and light experiment, one-way ANOVA was performed. Dunken's multiple range test was used to compare differences in treatment means.

3. Results and discussion

3.1. Number of seeds in a kilogram

The mean number of seeds in a kilogram and thousand seed weight were about 63,423 ± 2584 and 15.8 ± 1.6 g, respectively. The number of seeds in a kilogram found in our study differ from those (44,444) reported by Gebremedhin and Negash (1999). This indicates a difference of 18,979 seeds, which could be attributed to the difference in the geographic locations and the associated climatic and edaphic conditions between the source stands. Seed size of a species varies with site where trees in a stressed environment produce large size seeds, which is an adaptation that evolved over time (Begon et al. 2006).

3.2. Seed susceptibility to insect attack

The proportions of seeds attacked by insects ranged from 13.9% to 17.3% (mean = 16.7%) in tapped stands while from 7.7% to 19.17% (mean = 15.18%) in untapped stands. However, no significant differences were found between seeds collected from tapped and untapped stands ($P > 0.416$) and trees of different diameter classes ($P > 0.459$). In general, these results conform well to other similar studies carried out on *B. papyrifera* seeds from different geographical regions. For instance, the proportions of seeds attacked by insects from seeds of *B. papyrifera* collected from Tigray National Regional State, northeastern Ethiopia (Gebremedhin and Negash, 1999) and Eritrea (Ogbazghi, 2001) were 18% and 25%, respectively. The outcome of these studies may indicate the existence of natural predators of *B. papyrifera* seeds, which need to be identified through research.

3.3. Effects of tapping and tree size on seed viability

In general, seeds collected from trees in the untapped stands exhibited significantly higher germination percentage (mean = 59% ± 3.6%) than those from trees in the continuously tapped trees (mean = 49.3% ± 3.3%) (Table 1). Seeds collected from trees with intermediate diameter in untapped stands exhibited significantly higher germination percentages (64% ± 4.3%) than those from trees with the smaller (51.5% ± 1.6%) and larger diameters (47% ± 4.8%) (Table 1). Our results are in agreement with those reported from a similar study made in Eritrea where seeds from untapped trees exhibited significantly higher germination than seeds from continuously tapped trees (Ogbazghi, 2001; Rijkers et al., 2006). However, the interaction effect was not significant ($P > 0.153$), indicating that seed viability of different sized trees responded differently irrespective of stand management (tapping or non-tapping).

The significantly low germination percentage of seeds of trees from the tapped stands compared to the untapped stands prompts that the current tapping practices are affecting the physiology of the trees and, hence, their seed quality production, which is ultimately reflected in the viability of the seeds of the species. Tapping may cause the trees to allocate photosynthetic products (carbohydrates) to the healing of wounds and for the production of resins, which may lead to the production of poor and unviable seeds. A similar phenomenon has been reported from Eritrea (e.g. Rijkers et al., 2006). This factor, coupled with the high-pressure from livestock grazing, forest fire and prolonged frequent drought periods, strongly contributes to the overall lack of successful seedling recruitment of *B. papyrifera* in the dry woodlands of the Horn of Africa (Rijkers et al., 2006). These results imply that for future *B. papyrifera* plantation establishment programs, seeds should be carefully collected from untapped stands and trees with intermediate diameters to increase the chance of success.

Table 1
Germination percentage (%) of freshly collected *B. papyrifera* seeds from tapped and untapped stands and from trees of different diameter classes from Metema District, Ethiopia.

Tree size	Germination (%) by stand type		
	Tapped	Untapped	Mean
Large (30 cm DBH)	40 ± 5.9	54 ± 6.2	47 ± 4.8^a
Medium (20 cm DBH)	56 ± 5.9	72 ± 2.8	64 ± 4.3^b
Small (10 cm DBH)	52 ± 2.3	51 ± 2.5	51.5 ± 1.6^a
Mean	49.3 ± 3.3^a	59 ± 3.6^b	

Different letters across the last row and column indicate significantly different means; two-way ANOVA – Tree size: $F_{(5,2)} = 7.5$, $P = 0.004$; and Tapping: $F_{(5,1)} = 6.8$, $P = 0.018$.

Table 2
Comparison between untapped and tapped stands for proportion (%) of seeds of *B. papyrifera* that germinated after storage for different months under different storage temperatures.

Storage temperature (°C)	Storage period (months)			
	6	9	12	Mean
5	88 ± 2.4	24.5 ± 0.7	84 ± 3.8	65.5 ± 6.2^c
15	90 ± 2.5	60 ± 0.0	80 ± 6.9	76.6 ± 3.5^b
21	90.5 ± 2.7	97.7 ± 0.9	94 ± 1.5	94 ± 1.2^a
Mean	89 ± 1.4^a	60.8 ± 6.2^b	86 ± 2.8^a	

Different letters across last row and column indicate significantly different means; three-way ANOVA – Tapping: $F_{(17,1)} = 10.23$, $P = 0.002$; Storage temperatures: $F_{(17,2)} = 10.23$, $P = 0.0001$; Storage period: $F_{(17,2)} = 35.22$, $P = 0.0001$; and Storage temperatures x Storage period: $F_{(17,4)} = 24.26$, $P = 0.0001$.

3.4. Seed longevity

Significantly higher longevity of *B. papyrifera* seeds was exhibited by seeds stored at a storage temperature of 21 °C (94% ± 1.2%) than seeds stored at both 15 (76.6% ± 3.5%) and 5 °C (65.5% ± 6.2%) (Table 2). Similarly, the difference in longevity was significant for seeds stored at the storage temperature of 15 than 5 °C. Seeds from untapped stands exhibited significantly higher germination percentage (80.9% ± 4.1%) than those of tapped stands (76.6% ± 3.8%). Storage period had also showed significant effect on the longevity of *B. papyrifera* seeds where a significantly higher longevity was exhibited by seeds stored for 6 (89% ± 1.4%) and 12 (86% ± 2.8%) months than those stored for 9 months (60.8% ± 6.2%) (Table 2). Moreover, our analysis accounted for interactive effects of storage temperature and period where seeds stored at 21 °C and 12 months exhibited higher longevity (94% ± 1.5%) than other storage temperature and period combinations (Table 2). The higher germination percentage and, hence, seed longevity (> 94%) at 21 °C for the seeds collected from both untapped and tapped stands suggests that seeds of *B. papyrifera* can be stored for at least one year at room temperature without much loss in viability.

3.5. Effects of fire (heat) and light on viability of seeds

Significant ($P < 0.0001$) differences were found among mean germination percentages of seeds exposed to the different temperatures (Table 3). However, mean germination percentages of seeds exposed to temperatures of 40–100 °C did not show significant ($P > 0.478$) differences. Seeds exposed to 120–200 °C did not germinate at all irrespective of the exposure time (Table 3). Thus, heat

Table 3
Proportion (%) of seeds of *B. papyrifera* that germinated under different temperatures of dry heat.

Time (minute)	Control*	Temperature (°C)							
		40	60	80	100	120	150	200	Mean
10	–	82 ± 2.0	49 ± 3.5	63 ± 4.4	93 ± 3.4	0	0	0	41.1 ± 7.3[c]
20	–	97 ± 1.0	63 ± 3.4	91 ± 1.9	97 ± 1.0	0	0	0	49.7 ± 8.6[b]
30	–	92 ± 2.8	55 ± 3.4	95 ± 1.0	70 ± 3.5	0	0	0	44.6 ± 7.8[c]
60	–	96 ± 1.6	68 ± 5.9	89 ± 2.5	70 ± 8.2	0	0	0	46.1 ± 8.0[bc]
Control*	99 ± 1.0	–	–	–	–	–	–	–	99 ± 1.0[a]
Mean	99 ± 1.0[a]	91.8 ± 1.8[b]	59 ± 2.6[d]	84.5 ± 3.5[c]	82.5 ± 3.9[c]	0[e]	0[e]	0[e]	

* The control represents unheated seeds tested for germination in a similar procedure as others.

levels at and above 120 °C were lethal to *B. papyrifera* seeds indicating that seeds will be killed if sever fires (with temperatures of 120 °C and above) occur in the natural habitat of the species. Similar results were reported on *Acacia senegal* and other dryland species where significant decline in germination percentage of seeds was found when the seeds were exposed to higher temperatures (Teketay, 1996; Gashaw and Michelsen, 2002).

There was no significant ($P > 0.356$) difference in the mean germination percentage between seeds tested under light (99%) and dark (100%) conditions, suggesting that seeds lack light-imposed seed dormancy. This might explain the lack of persistent soil seed banks of *B. papyrifera* at its natural habitat (Eshete et al., 2005). The lack of seed dormancy could be a strategy for the seeds to germinate soon after dispersal following the rainy season in order to escape damage from fire during the following dry season. Annual human-induced fires occurring at the study site, could consume seeds on or in the soil (Uhl et al., 1982; Putz, 1983; Enright and Lamont, 1989; Garwood, 1989; Swaine, 1992; Ericksson et al., 2002; Eshete et al., 2005). The inflammable resin coating of the seed has also been suspected to increase the risk of seed mortality due to the recurrent fire (Eshete et al., 2005).

4. Conclusions

The result showed that both tapped and untapped stands produced comparable insect attacked seeds. Untapped trees yielded significantly higher viable seeds than continuously tapped trees, and trees with medium size (20 cm DBH) provided more viable seeds than bigger (30 cm DBH) and younger trees (10 cm DBH). Longevity of *B. papyrifera* seeds indicated significant difference in viability under three different temperature regimes (5, 15 and 21 °C), three storage periods (6, 9 and 12 months) and two tapping regimes (tapped and untapped populations). The storage of viable seeds of *B. papyrifera* is possible at least for one year with no loss in germination capacity of the species even at room temperature. The results also revealed that fire, which is a common phenomenon in the *B. papyrifera* dominated woodlands, can have lethal effects if the temperature produced by the fire exceeds 100 °C.

These findings suggest that: (i) new and improved tapping techniques that may result in better incense yield with minimum impact on the regeneration capacity of the species need to be developed; (ii) sufficient resting period between tapping cycles should be allowed for recovery of the species and production of viable seeds that will promote sustainable reproduction of the species; and (iii) intense fire with soil temperatures above 100 °C should be avoided.

Future research efforts focusing on reproductive biology of the species, site variation in terms of seed production, reducing the proportion of insect affected seeds, inventing a new tapping technique that has minimal impact on production of viable seeds and the tree itself are recommended. The results from such studies may ensure the sustainable production of frankincense with little impact on the population growth of *B. papyrifera*.

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