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Tapping height and season affect frankincense yield and wound recovery of *Boswellia papyrifera* trees

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ABSTRACT

Boswellia papyrifera (Del.) Hochst is a threatened tropical dryland tree species. It is the source of frankincense, valued for its industrial, religious and traditional uses. This tree species is reported as under threat due to mortality from wound and inappropriate frankincense harvesting techniques. Two experiments were conducted simultaneously in the lowlands of North Western Gonder Zone, Ethiopia. The first experiment aimed to understand the effect of tapping height and tree size on wound recovery and frankincense yield and the second experiment dealt with understanding the effect of tapping schedule on survival and frankincense yield of different tree diameter sizes. Larger trees tapped at 1 m above the ground had the fastest wound recovery and highest frankincense yield. Higher tree survival was observed when tapping and resting schedule was alternated over years. However, mortality was higher when trees were tapped in consecutive years, without a resting year. The mean frankincense yield was 78 and 535 g/tree/year for small and large trees, respectively. Our result suggested that tree size, tapping height and resting time all have a significant effect on frankincense yield and wound recovery. Alternate year tapping of larger trees, with resting every three years, and avoiding tapping small trees are recommended for best wound recovery, survival, and to ensure sustainable production of frankincense.

1. Introduction

Frankincense is an oleo-gum resin product collected from several species of the genus *Boswellia*. *Boswellia papyrifera* (*Del.)* Hochst is a well-known species valued for its frankincense. In addition to being a source of frankincense, *Boswellia papyrifera* is considered a key dryland tree species that successfully thrives in marginal dryland areas and offer livelihood opportunities to the local people (Mokria et al., 2017; Leminih and Teketay, 2003). The population of *Boswellia papyrifera* is facing several challenges in which its degradation is evident in Ethiopia and in other growing areas (Abiyu et al., 2010; Dejene et al., 2013; Eshete et al., 2005; Eshete et al., 2012; Lemenih et al., 2007; Tadesse et al., 2007). Although, pressures like uncontrolled grazing, deliberate burning, over exploitation, and expansion of commercial farming are causing the degradation of the species. Unsustainable tapping practices have also posed major threats by driving the early death of the tree.

Frankincense is collected from naturally occurring trees and inside state owned forests by cooperatives, public enterprises and companies. The mode of harvesting in most cases is by using tools such as axes and sharp knives that could result in injuries of the cambium and shorten the life span of the tree. Tapping was reported to negatively affecting both reproduction and natural regeneration potential as well as shorten the life-span of the tree (Eshete, 2002; Eshete et al., 2012; Mengistuet al., 2013; Ogbazghi, 2001; Ros-Tonen et al., 1995) *Boswellia papyrifera* is now considered an endangered species (Abiyu et al., 2010; Gebrehiwot et al., 2002).

The aim of this study was to evaluate the effects of tapping height and tapping schedule on wound recovery, survival and frankincense yield of young and mature *Boswellia papyrifera* trees in our study area. We hypothesized that current tapping practices are leading to the decline of the species in Northern Ethiopia.

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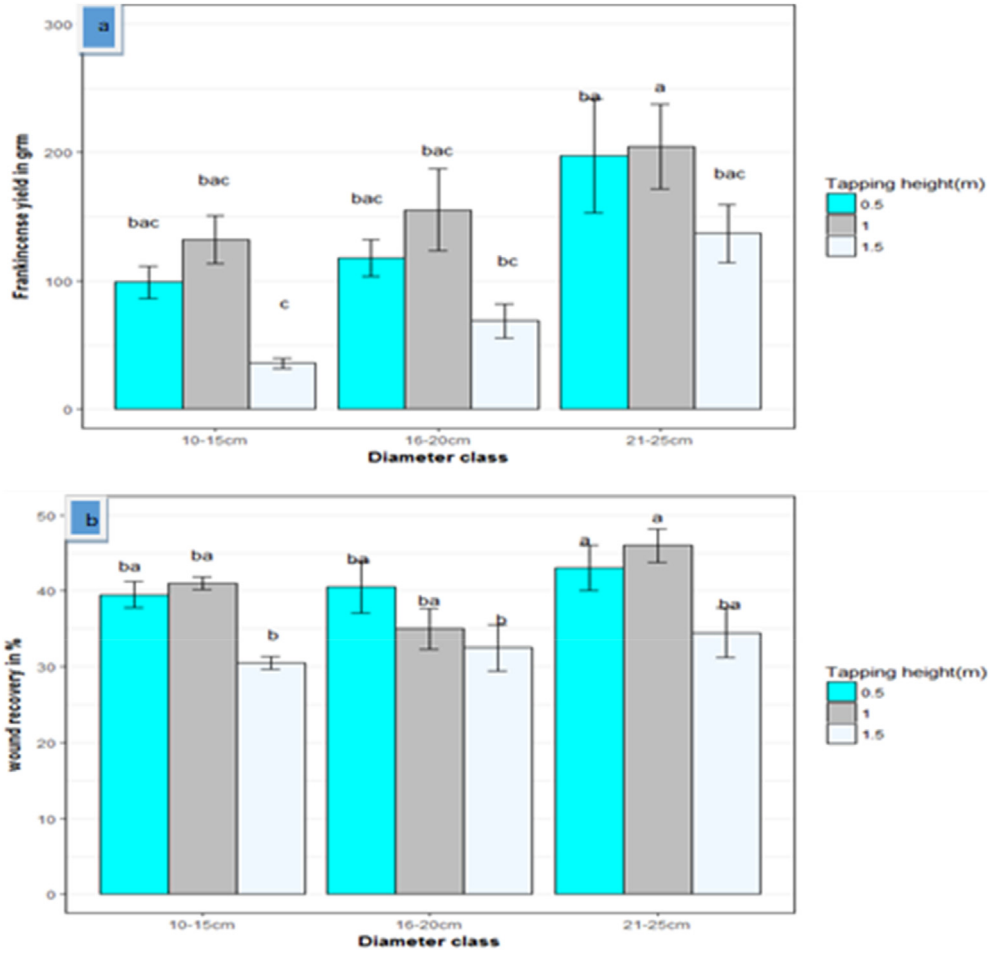

Fig. 1. a) Mean frankincense yield for *Boswellia papyrifera* tree per year, for different tree DBH sizes and tapping heights, b) mean wound recovery rate/year/trees for different tree size and tapping height.

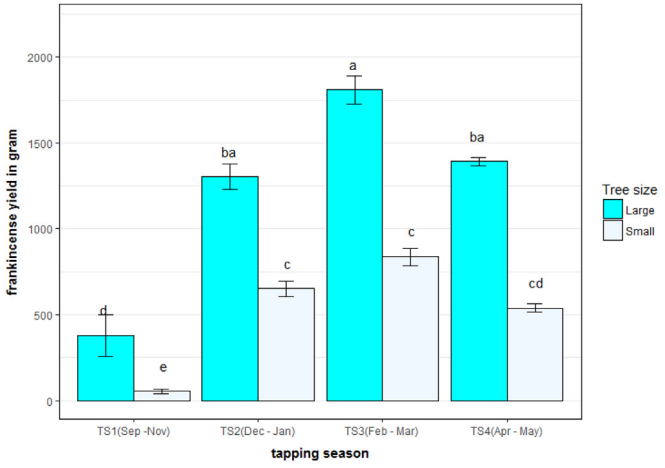

Fig. 2. Frankincense yield (g) of *Boswellia papyrifera* trees per tapping season (TS).

2. Methods of data collection and analysis

The research was conducted in Metema district (12°33.58′-12°41.53′N, 36°04.12′-36°18.84E), at two locations, namely Lemelem Terara and Meshah.

The first field experiment was conducted between 2009 and 2010. A total of 45 trees were selected based on their representativeness of the standing population. The selected trees were then sorted into three levels of size classes, based their Diameter at Breast Height (DBH), of 10–15 cm, 15.1–20 cm and 20.1–25 cm. The trees were subjected to tapping at three customary tapping heights: 0.5 m, 1 m and 1.5 m above ground. The wound recovery recorded after collecting the frankincense yield. The data were collected by rating the appearance and degree of cover of new tissue growth of the tapping spots. The rating includes from 0 to 25%, 25–50%, 50–75% and 75–100%.

A second, experiment was conducted between 2008 and 2011. Forty trees were selected based on their similar tapping history. The selected trees were sorted into size classes of DBH 10–20 cm (small trees) and DBH > 20 cm (large trees), because of a shortage of suitable trees to sample. The trees were allocated to four different tapping and resting categories (n = 5 for each combination of size and tapping schedule). The tapping and resting schedule includes: i) small and large trees tapped in each year, ii) small and large trees tapped one year and rest one year (tapping in alternate year), iii) small and large trees tapped for two years and rest one year, iv) small and large trees tapped for three years and rest one year. Frankincense yield data from each tree was collected from September to the end of May. The mean yield per year was calculated by considering the actual yield harvested and the years only when tapping were performed. Survival was also counted at the end of each season from each category.

Traditional knowledge showed that frankincense yield will be better and wound recovery will be fast when*Boswellia papyrifera* trees are tapped in two directions, in East and West directions only. Therefore, tapping was done in East and West directions only. Analysis of variance (ANOVA) and descriptive statistics were performed for the first experiment. For the second experiment, a General Linear Model (GLM),

Table 1
Mean frankincense yield for different tree size and resting period for *Boswellia* papyrifera trees.

Treatment	Mean yield in gram.
Large trees one year tapped one-year rest	535.30a
Large trees three years tapped and one-year rest	404.82ba
Large trees two years tapped and one-year rest	307.09b
Small trees one year tapped and one-year rest	282.50bc
Small trees three years tapped and one-year rest	164.82dc
Large trees every year tapped	151.86dc
Small trees two years tapped and one-year rest	147.97dc
Small trees every year Tapped	77.60d

R-Square	CV	Root MSE	YLD Mean	LSD	Critical t value
0.871756	25.80623	66.83644	258.9935	86.588	2.04841

Source	DF	Anova SS	Mean Square	F Value	Pr > F
Tapping season	3	449410.9854	149803.6618	33.53	< .0001
Size class	1	329589.6101	329589.6101	73.78	< .0001
Season*size class	3	51267.7533	17089.2511	3.83	0.0205

NB. Means followed by the same letter are not significantly different **at 0.05 probability level**.

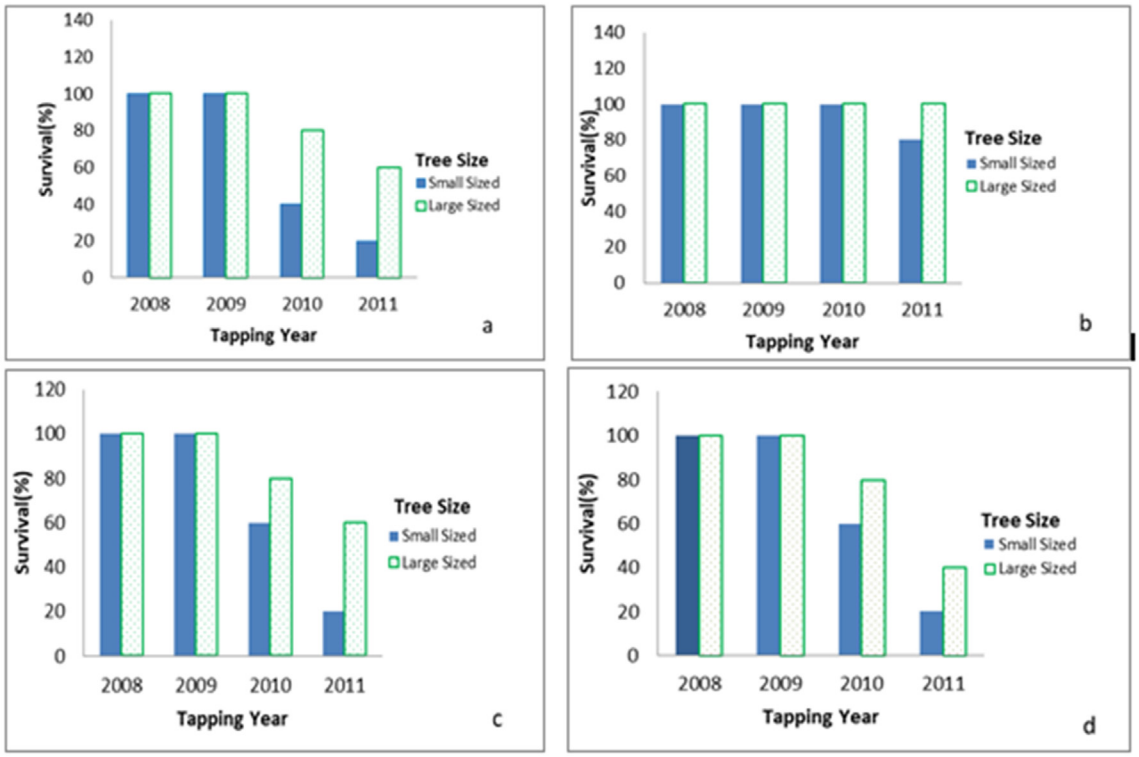

Fig. 3. Survival of trees a) tapped without resting, b) tapped one year and rested the next, c) tapped for two consecutive years and rested in the third, and d) tapped for three consecutive years and rested in the fourth.

procedure of SAS, was used. The analysis of variance was performed to find out variations among treatments. The predictors (independent) variables were tapping season, tapping height, tree size, resting period, whereas survival and frankincense yield were selected as the response (dependent) variables. LSD was used for mean separation.

3. Results

3.1. Experiment I

3.1.1. Effect of tree size and tapping height on frankincense yield and wound recovery rate

There was significant difference in mean frankincense yield between size classes and tapping heights (Fig. 1 a and 1b). Frankincense yield ranged from 35.7 ± 17.1 g (mean ± SD) to 204.3 ± 132 g/tree/year. Trees of DBH size 20.1–25 cm had higher frankincense yield (about 180 g) than smaller sized trees. Frankincense yield differed significantly among tapping heights. Tapping at the height of 1 m gave

Table 2
ANOVA model for frankincense yield (R-Square = 0.26, CV = 78.22, Root MSE = 104.28, Mean Yield = 127.38).

Source	DF	SS	MSE	F Value	Pr > F
Model	9	290268.141	32252.016	2.97	0.0045
Error	76	826394.551	10873.613		
Corrected Total	85	1116662.691			

ANOVA of Height, Diameter and Year for frankincense yield

Source	DF	SS	MSE	F Value	F
Height	2	90257.4656	45128.7328	4.15	0.0195
Diameter	2	137460.3633	68730.1816	6.32	0.0029
Year	1	59865.1671	59865.1671	5.51	0.0216
Height*Diameter	4	9719.4799	2429.8700	0.22	0.9245

better frankincense yield 164 ± 30.2 g than tapping at 0.5 (138 ± 42.6) or 1.5 m (80 ± 42.1 g) heights. However, for frankincense yield there was no significant interaction between tapping height and diameter (Table 2).

Wound recovery was significantly different when tapping was conducted across DBH size classes (Fig. 1b). The minimum and maximum mean wound recovery rates were 31%–46%/tree/year. Trees of DBH size 20.1–25 cm showed up to 46% wound recovery when tapped at 1 m height, which is 66% higher than the lowest recovery recorded. For a given diameter, wound recovery declines significantly when tapping was performed at 1.5 m.

3.2. Experiment II

3.2.1. Tapping season and resting period effect on frankincense yield

The peak frankincense yield was collected between February and March, with mean yield equivalent to 1810 ± 326.6 gm/year; Fig. 2). However, tapping in September to November showed the lowest frankincense yield. Overall, larger trees yielded more frankincense than small-sized trees.

A significant difference ($P < 0.0001$) in absolute frankincense yield (yield not adjusted to non-harvest years) was observed between different resting periods (Table 1). Higher frankincense yield was collected from large trees that were tapped in one year and left to rest for one year (alternate years with tapping and non-tapping years), and large trees tapped for three years and rested for one year. Smaller-sized trees tapped regularly without non-tapping years showed lower frankincense yield collection.

3.2.2. Effect of resting from tapping on the survival of trees

There was no difference in tree survival in the first two years for both small- and large-sized trees (Fig. 3). A difference in survival was observed in the third and fourth tapping year. At the end of the fourth year, survival of trees 10–20 cm DBH was 20% when tapped without resting, or when tapped for two or three consecutive years without resting. However, when tapping was followed by resting, the survival rate was 80% for these trees groups. For trees > 20 cm DBH, survival rate was 100% when a tapping year was followed by a resting year. Survival dropped to 40%, however, when tapping was performed for three years continuously without rest.

4. Discussion

Our study depicted faster wound recovery rates when larger trees were tapped, particularly at lower tapping positions. However, small tree size and tapping at 1.5 m showed lower wound recovery rate. This result is in agreement with the finding of Eshete et al. (2012) who reported lower wound recovery in small trees. This could be due to the fact that larger trees have sturdier bark, greater total carbon gain over time, and higher resource accumulation capacity in their stems, which makes them more resilient to any external forces. Mengistu (2011) also reported that small trees are less resilient to continuous tapping because they suffer carbon starvation due to their lower photosynthetic carbon acquisition capacity. We observed thicker bark at the lower stem height for larger trees. The presence of thick bark at the lower stem height could partially explain why larger trees attained better wound recovery potential. Although tree architecture is largely determined by genetics and site quality, larger-sized trees have more foliage, and therefore a greater surface area for photosynthesis.

A peak frankincense yield harvest was seen in tapping season of January–March, which is consistent with the findings of Eshete et al. (2012) who also reported a greater frankincense harvest in these months. However, the remaining tapping season showed lower frankincense yield. This might be attributed to the high rate of depletion in the resin associated with intensive tapping and collection.

Our study showed a significant difference in frankincense yield between tree sizes (Table 2). The frankincense yield collected from trees with larger diameter size was significantly greater than small-sized trees. The observed variation could be due to differences in their carbohydrate accumulation potential (Eshete, 2011; Mengistu, 2011). Similarly, lower tapping height could lead to higher frankincense yield from *Boswellia papyrifera* trees. The range of frankincense yield collected in our second experiment ranged from 78 to 535 g/tree/year. These values are less than the range of 41–1829 g/tree/year reported by Eshete et al. (2012) but greater than values reported by Tadesse et al. (2004) or Tilahun et al. (2011) (7–451 and 472 g/tree/year, respectively).

We found a significant difference in tree survival rate between larger trees tapped one-year, larger trees tapped three years, smaller trees tapped three years and rested for one year. A relatively better survival rate was observed in large trees tapped one year and three years and one-year rest. Conversely, small size trees tapped regularly without resting had lower survival rates. The wide variation in tree survival might be due to the difference in their storage ecology and their resilient to any external impact (Mengistu, 2011; Mengistu et al., 2013). Furthermore, frequent tapping without rest could lead to the loss of sucrose from the phloem prior to healing, thereby resulting in carbon starvation (Mengistu et al., 2013; Tolera et al., 2013)and reducing survival.

Our study is among few to investigate the effect of frankincense harvesting by tapping on the tree health. Our results suggested that continuous tapping will have a negative impact on the survival rate of smaller sized *Boswellia papyrifera* trees. Larger-size trees are more resilient to continuous tapping than smaller trees. Hence, to maximize frankincense yield and enhance the rate of wound healing, tapping should target larger diameter trees and lower tapping position, preferably below a metre from the ground. Additionally, a considerable resting period should be considered after each tapping year.

CRediT authorship contribution statement

Elias Cherenet: Data curation, Data curation, Formal analysis,

Writing - original draft. **Abrham Abiyu:** Writing - original draft, Writing - review & editing. **Ambachew Getnet:** Writing - review & editing, Data curation. **Kibruyesfa Sisay:** Writing - review & editing, Data curation. **Tatek Dejene:** Writing - review & editing, Data curation.

Declaration of competing interest

The authors fully agree as there is no conflict of interest over the submitted paper entitle with" Tapping height and season affect frankincense yield and wound recovery of *Boswellia papyrifera* trees ". Beside this, the manuscript is prepared by referring the guideline of journal of arid environment. Therefore, in case any other compliant arised we are eagerly ready to respond accordingly.

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