ASIAN JOURNAL OF FORESTRY
Volume 7, Number 1, June 2023
Pages: 10-16
E-ISSN: 2580-2844
DOI: 10.13057/asianjfor/r070102

Boswellia papyrifera a tree of economic importance in dry land Sudan: Dendrometric parameters and tapping characteristics

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Manuscript received: 29 September 2022. Revision accepted: 11 November 2022.

Abstract. *Dafa-Alla M, Abdelkari HA, Abuelbashar AI, Hassan MH. 2022. Boswellia papyrifera a tree of economic importance in dry land Sudan: Dendrometric parameters and tapping characteristics. Asian J For 7: 10-16.* We conducted this research in Abugadaf Natural Forest Reserve (ANFR) located within Blue Nile state, Sudan. The objectives were to examine dendrometric parameters and to analyze tapping characteristics for frankincense production. We randomly distributed 97 sample plots; in each, we counted *B. papyrifera* trees, measured their diameter at breast height (dbh), total height, bole height, and crown diameter, and examined the correlation between crown diameter and dbh. We examined 116 tapping spots made on 13 randomly selected trees. In each tree, we measured upper and lower tapping heights, calculated potentially untapped bole height, counted the number of tapping spots, measured their dimensions, recorded their directions, and compared mean numbers of tapping spots at four directions using one-way ANOVA (α=0.05). Results revealed that the distributions of dbh and the total height of tapped *B. papyrifera* followed a bell shape, and that of bole height and crown diameter followed a bell-shaped skewed to the right. Results revealed a significant (P=0.000) correlation between crown diameter and dbh (N=499) that trees were tapped at the four directions without significant difference (P=0.427) between mean numbers of tapping spots at the four directions. The study concludes that current tapping practice doesn't strictly adhere to recommended tapping guides, particularly with minimum lower tapping height and preference of concentration of tapping in east-west directions.

Keywords: *Boswellia papyrifera*, dendrometry**,** frankincense, tapping spots

INTRODUCTION

The genus Boswellia's economic importance stems from the production of frankincense (Sommerlatte and Wyk 2022), which expresses the characteristic aromatic natural oleo-gum-resins that occur in all its parts (Gebrehiwot et al. 2003) and used as incense. Frankincense production differs widely among the five chief producing species, with *B. papyrifera* being the main producing species at present (Bongers et al. 2019**).** Ecologically the species is important since it grows in harsh environments, where most tree species may not grow (Abiyu et al. 2010), are generally resource-poor regions with few livelihood alternatives, so harvesting frankincense in the dry season can contribute significantly to limited household income.

Frankincense is a natural resin obtained through incisions made into the trunk of trees of the genus *Boswellia*, enhancing the yield of resins. Usually, tapping involves deliberate shaving of a very thin, i.e., 2 mm deep and 4-8 mm wide, external circular layer of the bark along the stem (Figure 1), starting at 0.5m height using a hand tool known as Mengaf (Gessmalla et al. 2015) which is a hand tool with a metal end, about 2cm wide and a wooden handle (Figure 2) (Tadesse et al. 2004). Upon incision, the bark of *B. papyrifera* exudes a white milky liquid, which later hardens on exposure to air into globular or club-shaped droplets or tears (Figure 3) called frankincense (Lemenih and Kassa 2009).

Tapping process involves making repeated incisions into the bark over a series of months (Worku and Bantihun 2018) at a distance of about 30cm (Al-Aamri 2015) to 50cm (Tadesse et al. 2004). The particular details of the tapping, such as its duration, the time of year it is undertaken, and the interval between individual tappings, vary according to the species and the customs in the production area (Greenhalgh 2019). It is repeated four times, where the second and subsequent tapings are usually done at 15 - 30 days intervals. For small-size trees, tapping is done on the eastern and western sides (Gessmalla et al. 2015) and in four directions for larger trees.

The collection of resin starts after 30-35 days and extends up to the end of June, and generally, there are about 4-9 pickings per season, depending on the weather conditions (Ali et al. 2009). The hardened resin is removed at each tapping round, and the tapping wound is re-opened and enlarged (Tolera et al. 2013). Renewal of the wound at the correct interval of days is critical; otherwise, the old wounds may heal completely (Lemenih and Kassa 2011). During tapping, the cut surface gradually moves upward, and each year a fresh cut is started at a different site (Woldie 2011) immediately above the old wounds (Ali et al. 2009). Tree tapping is ceased 2-3 weeks before the rainy season (Gessmalla et al. 2015).

Figure 1. New (upper) and old (lower) tapping spots on the stem of *B. papyrifera.* Source: Abuelbashar (2020)

Figure 2. Mengaf is the traditional tool for tapping the *Boswellia* tree. Source. Ali et al. (2009)

Figure 3. Frankincense on the stem of *B. papyrifera* ready for harvest. Source. Abuelbashar (2020)

The number of tapping spots on each tree depends on the tree's diameter (Gebrehiwot et al. 2003) and height and foliage cover (Al Aamri 2015). The rules for forest use practices must be established to keep forests in good condition to sustain the provision of ecosystem services (Sist et al. 2014). Despite the economic and ecological benefits of the species, very little effort has been undertaken to develop the resource. Lack of reliable information is one of the major constraints that hamper species' efficient and economical development and use (Gessmalla et al. 2015). The underlying assumptions in this research were that current tapping intensity and frequency are appropriate while the tapping technique is traditional, wasteful, and needs technical improvements. The main objective of this study is to contribute to filling the information gap of the *B. papyrifera* resource base and tapping characteristics for frankincense production. Specific objectives are to analyze dendrometric parameters, explore diameter at breast height (dbh) and height class distribution, investigate current tapping practice characteristics, and explore statistical relationships between some measurable parameters of *B. papyrifera* in the Abugadaf natural forest reserve.

MATERIAL AND METHODS

Study area

We conducted this study in ANFR East of the Blue Nile River within Elrosairis locality, Blue Nile state, Sudan. It lies between longitudes 34° 50 45′ & 34° 54 45′ and altitudes 11° 25 10′ & 11° 30 10′ (Figure 4). With an estimated area of about 4,624.4 ha, it is one of a few dryland natural forests remaining within an extensive agricultural landscape in the state. ANFR is composed of thirteen tree species, including *Boswellia papyrifera* (Delile) Hochst., *Combretum aculeatum* Schweinf., *Lannea fruticose* (Hochst. Ex A. Rich.) Engl., *Sterculia setigera* (Delile), *Acacia Senegal* (L) Wild., *Anogeissus leiocarpa* (DC.) Guill. & Perr., *Balanites aegybtiaca* (L.) Delile, *Dichrostachys cinerea* (L.) Wight et Arn., *Acacia seyal* var *seyal* Delile, *Ziziphus spina-christi* (L.) Desf., *Hyphaene thebaica* (L.) Mart., *Adansonia digitata* L. and *Cordia sinensis* Lam. The most abundant tree species is *B. papyrifera*, with a maximum mean density of 51(±27) trees/ha (17.6%) relative to a mean tree density of 290 (±49) trees/ha at ANFR. *B. papyrifera* is one of the species in the forest that has been most utilized for economic benefits from frankincense production.

Dendrometric characteristics of *B. papyrifera*

We initially conducted a reconnaissance survey to explore the range of dbh of *B. papyrifera* trees and to estimate the mean minimum dbh used for tapping *B. papyrifera* for frankincense production. We randomly distributed 97 circular sample plots (0.10 ha) across the forest; in each tree, we counted *B. papyrifera* trees, measured their dbh (1.3m above ground level) to the nearest 0.1cm using a caliper, height to the nearest 0.1m using a Suunto clinometer (Suunto Corp., Finland) and crown diameter to the nearest 0.1m using a measuring tape. Next, we described the structure of the species using frequency distributions of dbh, total height, bole height, and crown diameter. Finally, we calculated the arithmetic mean diameters (D) of the trees using equation (1) (Mengich et al. 2020).

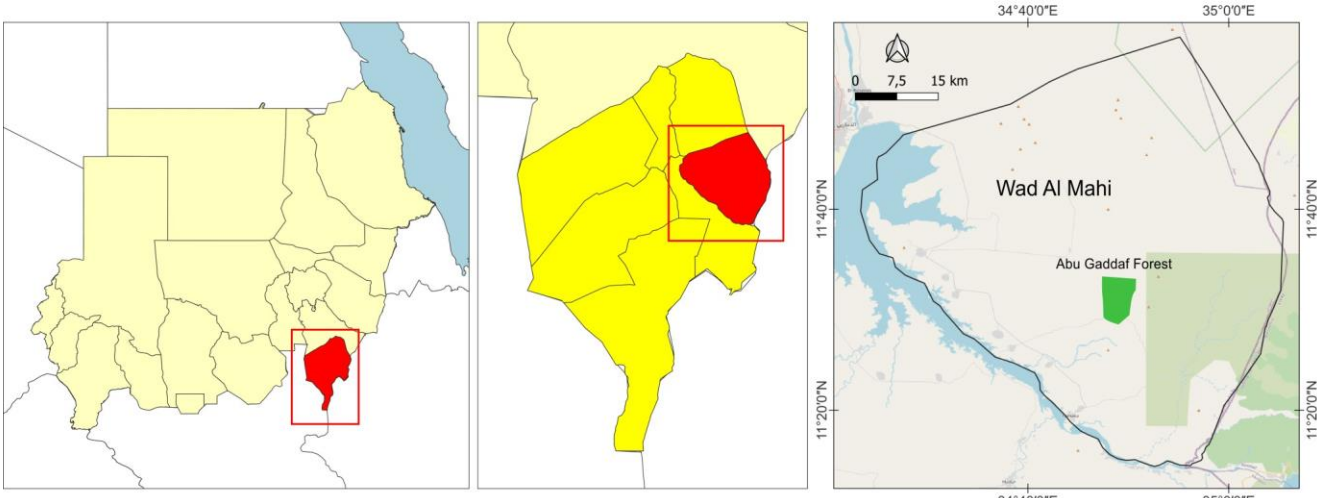

Figure 4. Study area in Elrosairis, Blue Nile state, Sudan

$$D = \frac{1}{n}\sum_{i=1}^{n} d_i$$

Where
d_i = diameter of the individual (i^{th}) tree
n = total number of trees in the plot

The dbh range was divided into ten dbh classes with a dbh class interval of 5cm. Then, we assigned each tree to an appropriate dbh class. Next, a clinometer will be used to measure the total height and bole (stem) of standing *B. papyrifera* trees.. then, the trees will be grouped into 5 total-height classes that begin at 2m and end at 14.5m with a class interval of 2.5m and seven bole-height classes that start at 1.0m and end at 7.9m with a class interval of 1.0m. Finally, it's calculated using the equation below (2).

$$H = \frac{1}{N}\sum_{n=1}^{N} h_i$$

The determination of the crown diameter of each tree was used as the average of two perpendicular widths through the crown vertical projection; the first measurement was along the direction of the longest branch of a tree. The second was along the direction perpendicular to the first measurement (Kimondo et al. 2014) using a tape measure to the nearest 0.1m. Next, the distributed crown diameters are into seven classes that start at 1.0m and end at 18.4m with a class interval of 2.5m. Finally, the Pearson correlation between crown diameter (cm) and dbh (cm) was examined.

In each sample plot, the total and pole heights are estimated to the nearest 0.1m and upper and lower tapping heights to the nearest 1cm. Then, a total of 116 tapping spots were examined by randomly selecting thirteen *B. papyrifera* trees. Then counted, the mean number of tapping spots per tree, measured their length, width, and depth dimensions, and determined their geographical directions was done. Finally, a one-way ANOVA was used to compare the mean number of tapping spots (α=0.05) made in the four tapping directions.

RESULTS AND DISCUSSION

Dendrometric parameters of *B. papyrifera*:

The mean dbh of *B. papyrifera* trees was 28.9cm (±7.4) (range 9.0-51.0cm) which is comparable to (Groenendijk et al. 2012) and is different from Abuelbasher (2020), who reported complete absence of trees with dbh ≥ 35cm southeastern Sudan and Gelaye (2012) who reported diameters of harvested trees from 11 to 30.5 cm. Figure 5 displays that the abundance of stems of tapped trees was very high in the middle, where 51.4% of the total individuals lie within two central dbh classes, 25-29cm, and 30-34cm. Trees with larger and smaller dbh were less abundant. The dbh distribution of tapped *B. papyrifera* was bell-shaped, displaying a higher number of individuals in the middle diameter classes and progressive reduction towards the lower and higher diameter classes. The same distribution pattern is reported by Gelaye (2012) in Ethiopia. The pattern of diameter class distribution indicates the general trends of population dynamics and recruitment processes of a given species (Abyot et al. 2014), with a bell-shaped diameter distribution indicating a hampered regeneration (Hido et al. 2020). The considerable number of individuals of the species in the middle diameter classes could be managed sustainably to improve their regeneration and produce resins. The diameter distribution of many large top canopy species does not follow a reversed-J tendency as they have relatively few individuals in the smaller sizes, suggesting little regeneration and recruitment of species in more recent years (Feyera et al. 2007). A short left-end tail of the dbh distribution curve is attributed to excluding untapped seedlings and saplings from the survey.

The results showed that the mean total height (N= 499) of the species was 7.9m (±2.2m) (range 2.0-13.0m) which is comparable to Gelaye (2012), who reported tree height from 4.57 to 13m. The distribution of *B. papyrifera* by total height demonstrates a higher number of medium-height individuals than short and tall individuals. The total height distribution (Figure 6) follows a bell-shaped pattern, with a maximum number of trees (16.2%) within a central bole height class 7.5-8.4m and decreasing numbers towards low and high total height classes. The short left-end tail of the total height distribution curve is attributed to exclusion of <10cm dbh seedlings and saplings from the survey; that at the right-hand tail demonstrates that some 15% of trees surpass the maximum total height of up to 12 m due to more favorable growing environments. The latter is slightly lower than Ethiopia's 14-16 m (Groenendijk et al. 2012).

The mean bole height was 3.1m (±0.3) (range 1.2-7.0 m). The distribution of bole height was bell-shaped (Figure 7) and skewed to the right, indicating that it was generally clustered around a low bole height class. 80.2% of total individuals lie within the lower three bole-height classes with fewer frequencies in higher ones. The short left-end tail of the bole height distribution curve is attributed to the presence of a few very large dbh resin-producing trees in the survey. Therefore, the species can be categorized with progressively declining numbers of trees with increasing bole height.

The results revealed that the mean crown diameter of *B. papyrifera* was 7.4m (±3.2) (range 1.0 - 16.0m) which was relatively higher than the 4.5 m reported by Gelaye (2012). The distribution of the crown diameter took a bell shape (Figure 8), skewed to the right. 85% of trees lie within the first four crown classes, and only about 15% of tree crowns frequencies lie within the three larger crown classes towards the right end. Crown diameter indicates that most *B. papyrifera* individuals are medium size trees. Analysis of Pearson's two-tailed correlation between crown diameter and dbh (N=499) revealed a significant (α=0.01) positive correlation (P=0.000, r= 0.758). The result supports the earlier findings of Schrender et al. (1993) that dbh is correlated to crown diameter.

Characteristics of current tapping practice

Results unveiled that tapping of frankincense tree at ANFR was made at a minimum dbh of 9.0 cm and up to 51.0 cm, comparable to 9.0-45.0cm reported by Eshete et al. (2005). However, this result contradicts the commonly applied tapping guide of a minimum tapping dbh of 10.0cm. The cessation of tapping on small, younger trees (10-15 cm) is recommended, as small trees have a low frankincense yield. Tapping causes more physiological stress to smaller trees than larger trees (Eshete et al. 2012), and they may not be able to recover their wounds after tapping (Abiyu et al. 2010). Prohibiting tapping trees with small dbh allows them to grow to a larger, more productive size and reproduce without interference (Gonzalez 2020).

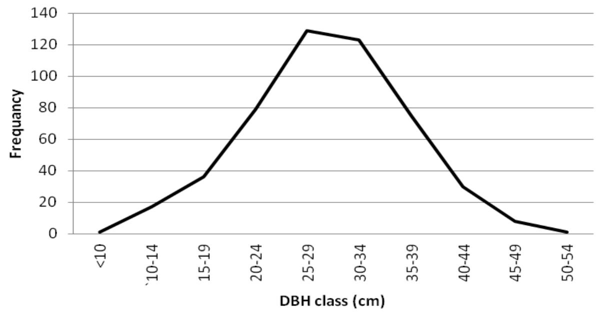

Figure 5. Distribution of *B. papyrifera* in Abugadaf Natural Forest Reserve by DBH classes

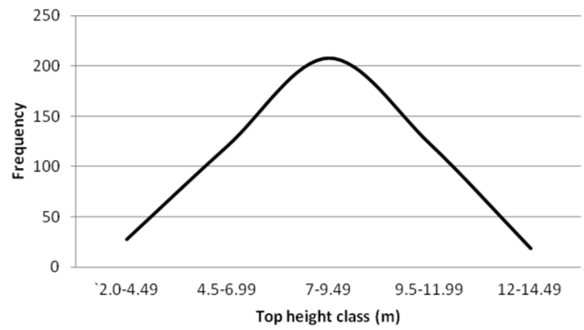

Figure 6. Distribution of *B. papyrifera* in Abugadaf Natural Forest Reserve by total height classes

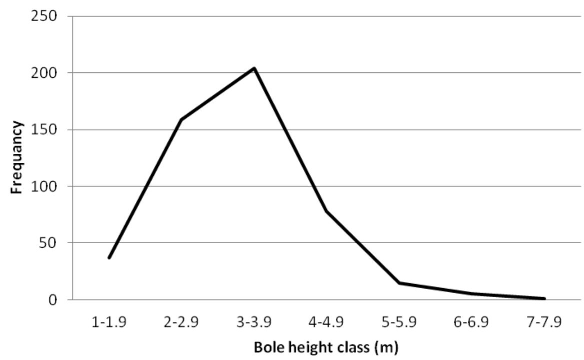

Figure 7. Distribution of *B. papyrifera* in Abugadaf Natural Forest Reserve by bole height classes

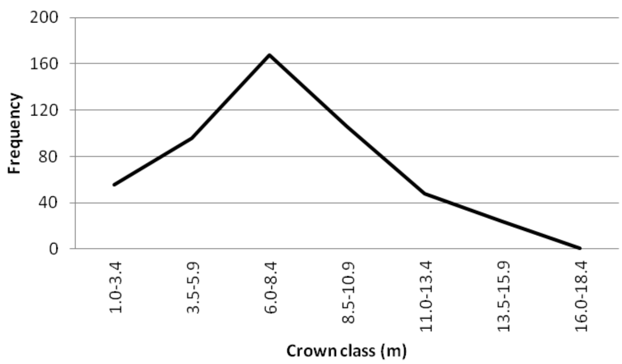

Figure 8. Distribution of *B. papyrifera* at Abugadaf Natural Forest Reserve by crown diameter

The results of this study revealed that mean upper and lower tapping heights (N=492) were 1.76m (±0.13) (range 1.05-2.20m) and 0.64m (±0.15) (range 0.3-1.0m) (Figures 9 and 10), respectively. Generally, the estimates of mean tapping heights fall within the range of the tapping heights of 0.50-2.0m applied in the local practice (Mengistu et al. 2013). With a mean bole height of 3.1m, the potential tapping height (over 0.64m mean lower tapping height) under current practice was 2.46m. Therefore, the mean actually tapped part of the bole height was 1.12m (±0.2) (range 0.5-1.6m), equivalent to 45.5%. The result implies that more than half of the potential tapping height was untapped as it was out of reach of tappers, and it remains a potential for tapping, which may help in better distribution of tapping spots for a better frankincense yield. That is of particular significance as close to 20% of the trees fall within bole height classes bigger than the mean bole height of the forest. In the current tapping practice in Sudan, the tree's height is not a determinant factor for the number of wounds since the laborers tap into the reachable parts of the trees (Nour 2008). The traditional practice of tapping requires innovative techniques to reach higher parts to maximize the use of bole height. The resin yield of *B. papyrifera* can be improved by modifying the tapping techniques (Ali and Gebauer 2007), tools, and skills.

While minimum and maximum numbers of tapping spots per tree were 1 and 12, results revealed that the mean number of tapping incisions per tree was 9.0(±3.0). The result generally follows the recommended tapping intensity per tree of 6-16 in Ethiopia (Abiyu et al. 2010, Lemenih and Kassa 2011), 6-10 in southeastern Sudan (Nour 2008 and 6-15 in West Sudan (Abtew et al. 2012) The result may be well understood provided that only 10.8% of the trees fall within small dbh class of <20 cm which is recommended to be tapped at two spots, one in each of east and west directions, 41.7% and 47.4% of trees fell within dbh class of 20-29 cm and >30cm, respectively, where the recommended tapping intensities are 3 and 4 tapping spots per a direction per tree (Gebrehiwot et al. 2003).

Results disclosed that trees were tapped on average at nine spots in the four directions with a mean of 3 spots in the East and 2 in each of the other three directions. The intensity of tapping is predominantly in the East, equally followed by North and South, and lower in the West direction (Figure 11). All-direction tapping of trees illustrates the dominance of trees with larger dbh (55%). In addition, resin yield per tree increases significantly with several tapping spots (Gelaye 2012). Table 1 displays a one-way ANOVA of the mean numbers of tapping spots (N=116) between four directions (α=0.05). One-one ANOVA revealed no significant difference (p=0.427).

The mean length, width, and depth of end-of-season tapping incisions were 6.6cm(±2.5) (range 3.0-17.0), 4.6cm(±1.3) (range 2.0-9.0), and 4.3mm(±1.6) (range 1.0-8.0), respectively. Tapping has recently intensified since the number of tapping wounds, and their dimensions have increased, leading to severe damage of many B. papyrifera trees and reduced production of viable seeds (Ogbazghi 2006).

Currently, due to the high demand for frankincense, up to 27 tapping spots are made per tree in some commercial sites (Kebede 2010). Recently, more tapping spots per tree and more tapping rounds per season are becoming common (Eshete et al. 2012) may be due to increasing global and domestic demand for frankincense**.**

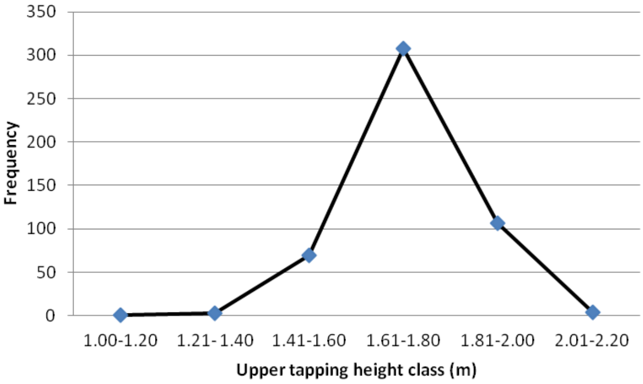

Figure 9. Distribution of *B. papyrifera* trees at Abugadaf Natural Forest Reserve by tapping upper-height

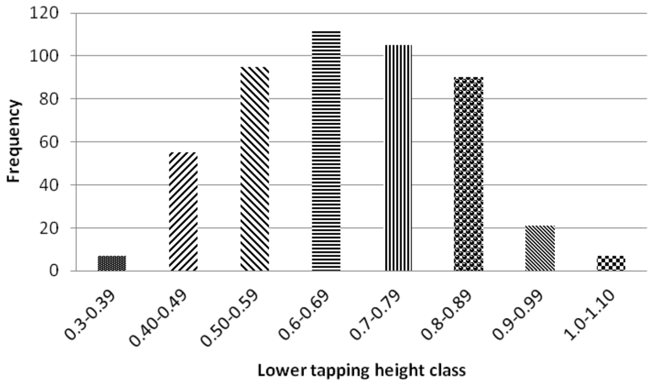

Figure 10. Distribution of *B. papyrifera* trees at Abugadaf Natural Forest Reserve by tapping lower-height

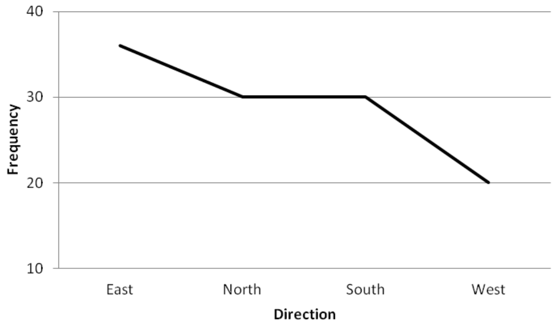

Figure 11. Frequency of tapping spots in the direction at Abugadaf Natural Forest Reserve

Table 1. One-way ANOVA of the direction of tapping and number of tapping spots

Sources of variation	Sum of Squares	df	Mean Square	F	Sig.
Between the direction of tapping	41.775	3	13.925	0.934	0.427
Within tapping directions	1669.217	112	14.904		
Total	1710.991	115			

The research concludes that the dbh distribution of tapped *B. papyrifera* is dominated by trees in the middle dbh classes that could be managed sustainably to improve their regeneration and production of frankincense. There is a significant and positive correlation between crown diameter and dbh, which calls for a better understanding of the influence of tapping on physiology and biomass production, particularly for small frankincense-producing trees. The current tapping practice of *B. papyrifera* for frankincense production doesn't firmly follow recommended tapping guides. Considerable bole length is currently unutilized as it is out of laborers' reach. The study recommends the development of a tapping protocol that maintains the resource base and sustains frankincense production. The protocol should emphasize the improvement of tapping techniques, tools, and skills.

ACKNOWLEDGEMENTS

The authors acknowledge the support from the Ministry of Higher Education and Scientific Research, Sudan, for financing the research project titled: "Analysis of production economics, value chain and export potentials of resin from *Boswellia papyrifera* (Del.) Hochst. forests in Blue Nile State, Sudan". They acknowledge the logistical support from the Forest National Corporation, too.

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