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Frankincense a Non-Wood Forest Product of Economic Importance in Sudan: Harvest Population, Tapping System and Yield from a Natural Mountainous Boswellia Papyrifera Forest

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Abstract

We conducted this research at Jebel Elgarrie Natural Forest Reserve (JENFR) in southeastern Sudan. We investigated harvest population, examined tapping system and quantified Frankincense yield from Boswellia papyrifera. For data collection we: a) randomly distributed 97 sample plots where we measured diameter at breast height (dbh) and bole heights (N=170), b) selected 119 trees, measured their tapping heights and collected frankincense yield c) scrutinized the direction of first-time tapping (N=16), and d) examined 237 tapping spots, measured their dimensions, and computed their frequencies per tree, per direction, and per dbh class. Results disclosed that mean dbh and bole height were 26.8(±12.5) cm and 3.5(±1.1) m, respectively, minimum tapping diameter was 11(±7.3) cm, and untapped length of the bole was 49.7%. About 96.6% of trees were lower tapped at recommended height, while none was upper tapped above 2.2m. Mean Frankincense yield was 145.8(±115.2) g/tree/year, positively correlated with dbh (r=0.44, p < 0.01). Mean number of tapping spots per tree (9±3), was positively correlated (r=0.61, p <0.01) with dbh, while, mean numbers of tapping spots per dbh size class were much higher than assumed in traditional harvesting. Chi-square test (α=0.05) revealed that first-time tapping of trees was equally done at four directions. The research concludes that while minimum tapping diameter and lower tapping height followed research recommendations, tapping intensity, direction of first-time tapping and dimensions of tapping spots were not. Avoiding these flaws requires improvement of tapping techniques, training of tappers to improve tapping skills, close monitoring and follow-up on tapping procedures.

Keywords: *Boswellia papyrifera, frankincense, tapping, Sudan*

1. Introduction

Boswellia Roxb. is a genus of moderately-sized, deciduous flowering trees and shrubs in the family Burseraceae, encompassing 20 species (Morka, 2024). *Boswellia* is native to arid regions of the Arabian Peninsula, east Africa, and India (Gonzalez, 2020) renowned for its aromatic resin. *Boswellia paprifera (Del.) Hochst.* stands as the exclusive species of the *Boswellia* genus naturally existing in Sudan (Ballal, 2011).

Frankincense or gum Olibanum is an aromatic oleo-gum-resin obtained from the bark of trees belonging to the genus *Boswellia*. It is exuded naturally due to pressure created within the bark by extreme natural conditions (Singh et al., 2024), but especially oozes out when incisions are made into the living bark of trees (Sharma, Singh & Baghel, 2024), and solidifies into globular, pear or club shaped tears upon exposure to air.

The process of resin extraction from trees is called tapping, and consists of making wounds in the stems of living trees to remove the bark and collect the resin that flows out from the exposed resin ducts (Sharma, Parasad, Pandey & Giri, 2018). Trees generate resin as a defence mechanism to heal and seal their bark following natural or human-induced injuries (Davison, Bongers & Phillips, 2022, Guta, Tan & Zhao, 2024) to prevent the attack and spread of pathogenic microorganisms. Harvesting frankincense is a meticulous process that involves specific timing and techniques (Fatima, Ramani, Vijayasundaram & Sivamani, 2024), influenced by natural, institutional and technical factors. The key characteristics of sustainable resin harvest are that it is seasonal, with mild to moderate intensity tapping, and occurring in areas with strong land tenure (American Herbal Products Association [AHPA], 2023).

Frankincense resin is an internationally celebrated NTFP due to its non-toxic, biodegradable and eco-friendly properties, making it suitable for use in various industries (Sharma et al., 2018). It is primarily derived from five *Boswellia* species, with *B. papyrifera* being the most prominent producer (Bongers et al., 2019). It is a multi-purpose tree species with Frankincense standing as the economically pivotal product. It significantly contributes to livelihoods of local communities, where harvesting, processing, and trade of frankincense create jobs, supporting roles like collectors, processors, traders, and transporters (Fatima et al., 2024). The arid and semi-arid regions where frankincense trees thrive are generally lacking in resources, with limited livelihood options available, making the harvest of frankincense during the dry season a significant source of income (Davison et al., 2022).

The production of oleoresin faces challenges related to tree growth, climatic conditions, unsustainable harvesting practices, and gaps in the market supply chain (Al-Harrasi, Khan, Asaf, & Al-Rawahi, 2019). Pressures such as unregulated grazing, deliberate burning, overexploitation, the expansion of commercial agriculture, and inadequate policies contribute to the decline of species. Over-tapping, which involves making too deep or too many tapping spots, carried out too frequently than is traditionally practiced for sustainable harvesting, severely weakens the trees (Sommerlatte & Wyk 2022; Eshete, Sterck & Bongers, 2012). The multitude of uses that frankincense provides has created a global demand motivated by the rising consumer preference for natural and organic products across fragrance, cosmetics and healthcare industries (Price et al., 2024).

In Sudan *Boswellia papyrifera* is found south of latitude 14° N in hilly areas in Blue Nile, South Kordofan and South Darfur states. In the Blue Nile State it spans across 16 forests with varying stock densities, where its populations has dwindled during the last decades, mainly due to an increasing human population, resulting in the conversion of woodlands into agricultural fields, increasing livestock pressure hampering natural regeneration (Gessmalla, Raddad & Ibrahim, 2015), forest fires, illegal tree cutting, and over tapping for frankincense production. Resin harvesting is made during the dry season, where other sources of income generation aren't available, encourages local people to be involved in resin production. While it is a secondary occupation for nearly all producers, cash income from gum and resin contributes for reduction of poverty with about 23% (Abtew, Pretzsch, Secco & Mahmoud, 2014) in Sudan. Frankincense is traded both domestically and internationally in its raw state as the country has neither industrial applications, nor value-added processing**.** Resin nodules are sorted into high quality grades for export and other inferior grades for local markets (Ballal, 2011).

Tapping season and tenure as two characteristics of sustainable harvesting of frankincense in Blue Nile are well established, however, tapping system as the third characteristic is not well studied and documented. Despite the widespread presence of *B. papyrifera* and its significant socio-economic and ecological benefits in Sudan, there is a lack of detailed records on harvest population, tapping characteristics, frankincense yield, and the factors that influence its production. This research endeavour aims to address the knowledge gap by investigating the characteristics of harvest population, harvesting system in terms of season, tenure and tapping, and examine yield of frankincense from *B. papyrifera* trees and its relationships with some tree measurable parameters.

2. Materials and Methods

Blue Nile State lies between latitudes 9° 30'N & 12° 30'N and longitudes 33° 5'E & 35° 3'E (Abdalla and Gessmalla, 2018). The major land uses in the state are agriculture, forests, pastoralism and residence. The main forest ecosystems in the state are dry land and riparian forests with an estimated total area of 1.07 out of a total state area of 4.22 million ha (FAO, 2015). The state has been for centuries a theatre of land use and land cover changes where forests have been cleared to pave the way for crop production encouraged by national polices that aim at food security and export earnings (Dafa-Alla et al., 2024).

We conducted this study in JENFR which lies between latitudes 11° 46' N & 11° 50'N and longitudes 34° 36' E & 34° 42' E (Fig. 1). With an estimated total gazette area of about 5040 ha, 20% stocked with *B. papyrifera* (Glen, 1996), it is one of a few dry-land natural forests remaining within an extensive agricultural landscape in the state. The topography of forest is a mixture of a series of mountains and plateaus that is generally characterized by savannah woodland formations. The current main formal management objectives of the forest are production of frankincense from *B. papyrifera* (Del.) Hochst. as the single species of most economic importance in the forest and protection of environment (Dafa-Alla et al., 2022).

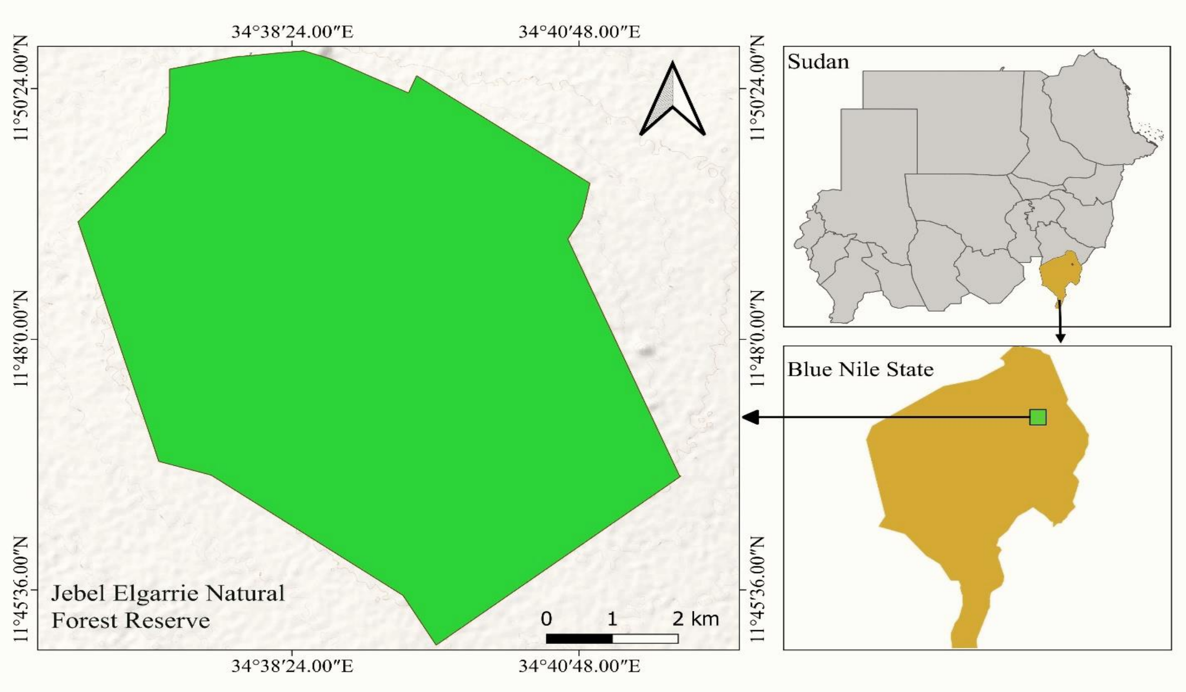

Figure 1. *Location map of Jebel Elgarrie Natural Forest Reserve*

2.1 Data Collection

2.1.1. Harvest Population and Characteristics

We carried out a survey to explore the range of diameters at breast height (dbh) (1.3m above ground level) over bark of *B. papyrifera* and to estimate minimum dbh used for first-time tapping for frankincense production. Then we randomly distributed 97 circular sample plots (0.1 ha) across the forest. In each sample plot we counted and recorded frequencies of mature (dbh≥10cm) *B. papyrifera* trees, measured their dbh to the nearest centimetre using a calliper, and bole height to the nearest 0.1 meter using a Suunto clinometer (Suunto Corp. Finland).

2.1.2. Tapping Diameter and Heights

We randomly selected 119 tapped *B. papyrifera* trees, measured upper and lower tapping heights to the nearest cm using a measuring tape. We calculated tapped length of the bole as the difference between mean upper and lower tapping heights, and mean untapped length of the bole as the difference between mean bole heights and mean upper tapping heights. We explored correlation of dbh with number of tapping spots and with untapped length of bole.

2.1.3. Number, Direction and Characteristics of Tapping Spots

We examined a total of 237 tapping spots made on randomly selected thirty *B. papyrifera* trees, assigned them to different dbh classes, counted number of tapping spots per tree, per direction and per dbh class; and measured their length (cm), width (cm) and depth (mm). A subtotal of 16 tapping spots were made on trees of small dbh class (10-14cm) that were first-time tapped, for which we used Chi-square test to examine whether these tapping spots are equally distributed on all directions.

2.1.4. Frankincense Yield

We collected resin yield from the 119 trees which were then assigned to their respective dbh classes. We calculated resin yield on the basis of dry weight, where collected resins were air seasoned for two weeks in the field and weighted using a digital weight balance with a precision of 0.01g. The annual frankincense yield (g/tree/year) was then taken as the sum of frankincense five collections made throughout the production season. We explored correlation of tree dbh (cm) with frankincense yield (g).

3. RESULTS

3.1. Harvest Population and Characteristics

Results revealed that mean dbh, bole height (N=170) and minimum tapping diameter (N=119) of *B. papyrifera* were 26.8(±12.5) cm, 3.5(±1.1) m, and 11.0 (±7.3) cm, respectively. Findings disclosed that in the current harvesting system only trees with dbh≥10cm are selected for tapping and harvesting season started in September and continued up to June of the following year, while tapping was started in October, repeated five times, with the original tapping spot refreshed and enlarged in each subsequent tapping round.

3.2. Tapping Diameter and Heights

Results depicted that minimum dbh of tapped trees was 11(±7.3) cm, mean values of lower and upper tapping heights were 0.7(±0.1) m and 1.8(±0.2) m (N=119), respectively, and the mean tapped and untapped bole lengths were 1.1(±0.2) m, and 1.7(±1.1) m, respectively, resulting in a ratio of mean untapped length of 49.7%.

3.3. Number, Direction and Characteristics of Tapping Spots

Figure 2(a) illustrates that about 3.4% of trees were tapped below the established lower tapping height of 0.5m, 95% between 0.5m and 0.94m, while 1.6% were tapped at upper heights.

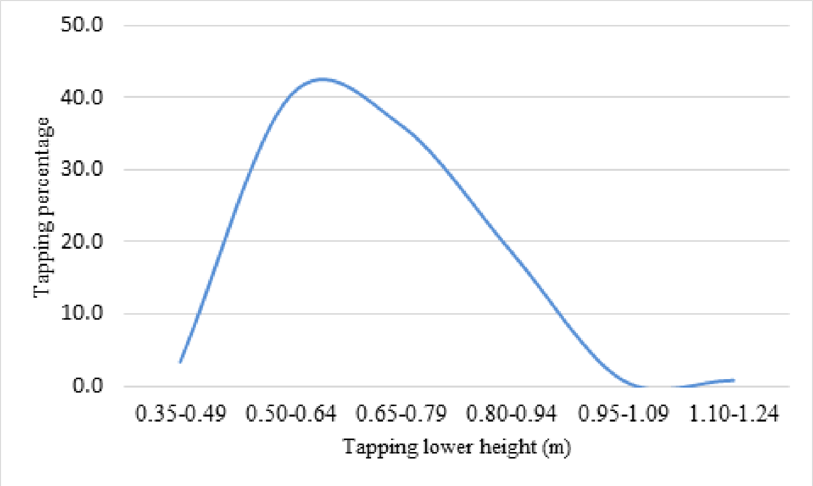

Figure 2(a). *Relative percentage of lower tapping height*

Figure 2(b) shows that all trees were upper tapped below a bole height of 2.2m with maximum frequency lies within 1.8m -1.9m upper tapping height class.

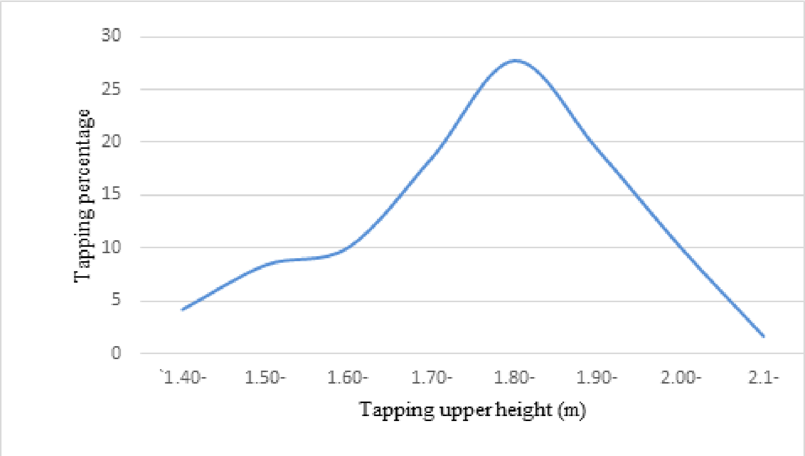

Figure 2(b). *Relative percentage of upper tapping height*

Figure 3 illustrates the relationship of untapped bole length (%) with dbh classes. Results revealed significant negative correlation (Pearson, r = -0.29, p < 0.01) of untapped length of the bole with tree size.

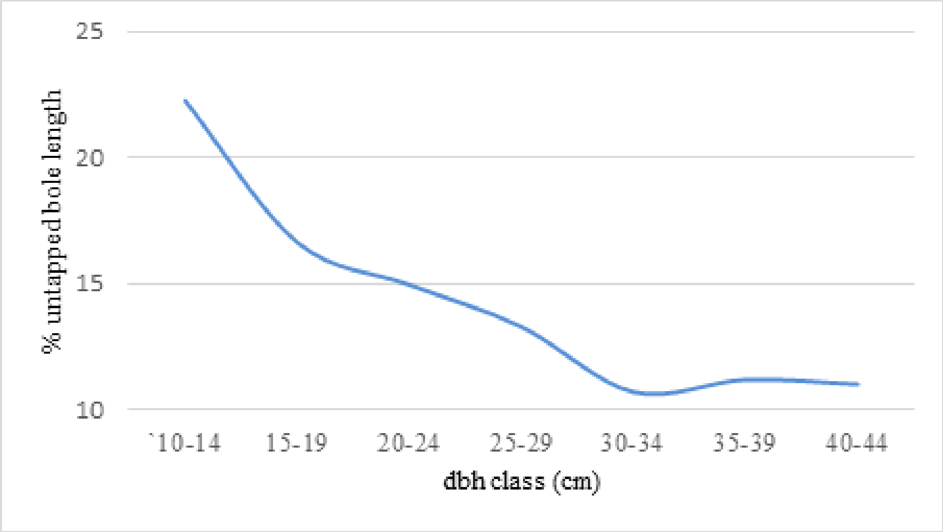

Figure 3. *Relative percentage of untapped bole length per dbh classes*

Total numbers of tapping spots in a season made on the 30 randomly selected trees were 59, 67, 48, and 63 at North, East, West and South directions, respectively, with a mean number of tapping spots/tree of 9 (±3) (N=119). Number of tapping spots showed a significant positive correlation (Pearson, r = 0.612, p < 0.01) with dbh class size. Mean numbers of tapping spots per dbh size class of trees varied between 6, 8, and 12 for small- (10-19cm), medium- (20-29cm) and large-dbh (30-44cm) trees, respectively (Fig. 4).

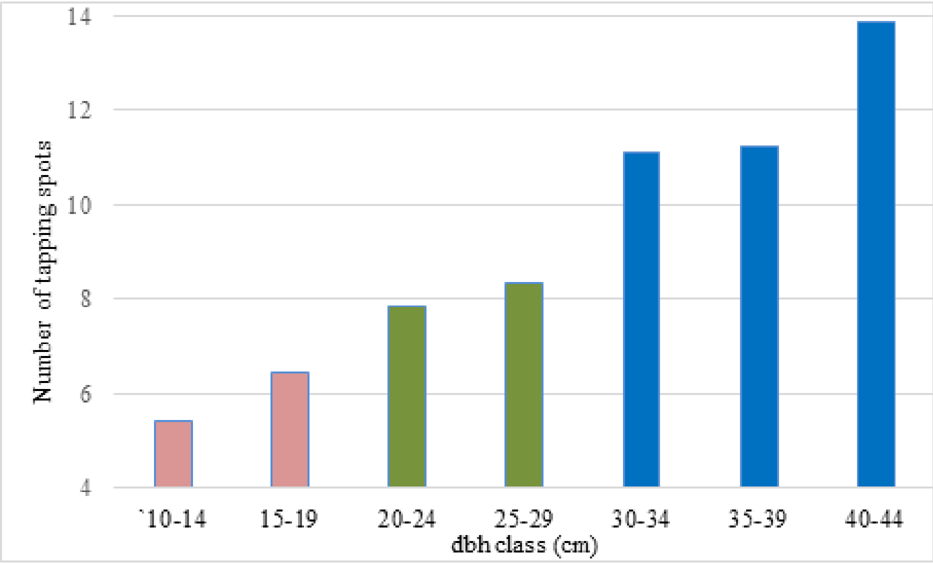

Figure 4. *Mean number of tapping spots per dbh class of B. papyrifera*

Results revealed that mean width, length, and depth of tapping spots were 3.5(±0.9) cm, 4.3(±1.5) cm, and 3.5(±1.2) mm, (N=237), respectively. Kruskal Wallis test (N=16) disclosed no significant difference (Chi-square = 3.151, p < 0.05) in the distribution of tapping spots cut at the four directions on first-time tapped trees.

3.4. Frankincense Yield

Results revealed that mean annual frankincense yield was 145.8 (±115.2) g (N=119). It was low (68.6g) for small-dbh trees (10-14 cm), then followed an increasing trend to reach maximum (277.9g) for trees within intermediate dbh-size class (35-39cm) and levelled off with large-dbh trees, thereafter (Fig. 5). While, wide variability in frankincense yield was noticed between trees in the same dbh class in JENFR, mean frankincense yield showed a significant positive correlation (Pearson, r = 0.44, p <0.01) with dbh class.

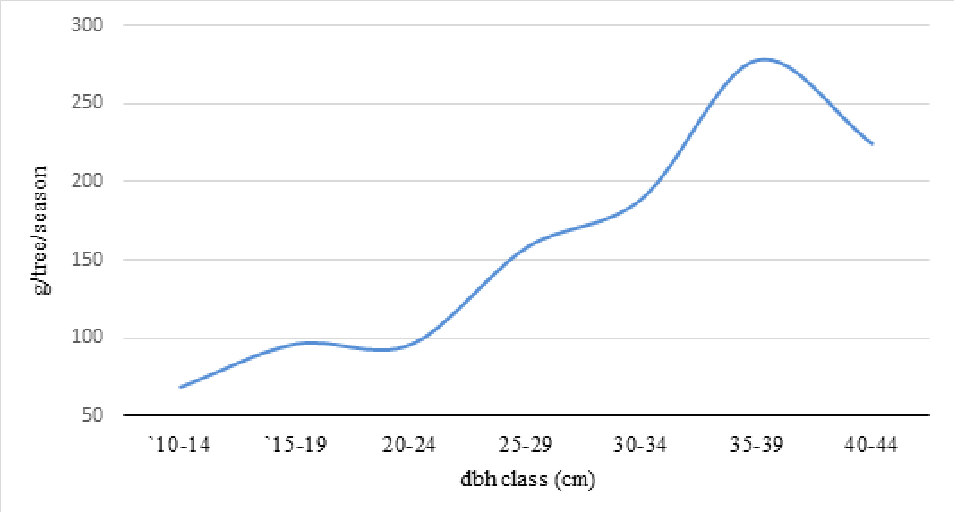

Figure 5. *Relationship of mean frankincense yield and dbh classes of B. papyrifera*

4. DISCUSSION

4.1. Harvest Population and Characteristics

Boswellia woodlands at JENFR are state property under the technical supervision of the FNC, which has legal control over the resource. The harvesting season of frankincense as in JENFR commences by producers' gaining legal access to *B. papyrifera* forest land through production permits provided by the FNC for a fee, usually during September to mark the start of harvesting season that ends up by June of the following year. Tapping is a cyclical operation that begins in October following shedding of leaves, repeated at between 15 and 30 days intervals (Ali, Fadl & Adam, 2009) and ends 2-3 weeks before the rainy season (Gessmalla et al., 2015) because Frankincense resin is easily damaged by rain so it is harvested only in the dry season (Coder, 2024). Collection of resin starts after 30-35days from the first tapping. It is done every two or three weeks with shorter periods during hot weather (Khamis, 2001).

4.2. Tapping Diameters and Heights

A minimum dbh of 11.0 (±7.3) cm for tapping is observed in JENFR. It follows tapping guides that minimum dbh of first-time tapping threshold is ≥10 cm in the current tapping system. The latter is analogous to that in Ethiopia (Groenendijk et al., 2012) and Somalia (DeCarlo, Ali & Ceroni, 2020).

While the mean lower and upper tapping heights computed at JENFR are consistent with those at Abugadaf Natural Forest Reserve (AGNFR) (Dafa-Alla et al., 2023), approximately 3.4% of trees in JENFR are tapped below 0.5m in contrast to established lower tapping height of 0.5m (Ali et al., 2009; Gessmalla et al., 2015). Tapping was concentrated at 1.8-1.89m and 1.90 -2.00m upper tapping height classes. This is attributed to the common practice of placing new tapping spots above old ones made in previous seasons (Ali et al., 2009; Lemenih & Kassa, 2011; Eshete et al., 2012; Lema et al., 2024; leading to an upward shift in tapping height. Heights above 2.2m were out of convenient reach of tappers with current tapping technology.

Compared to 45.5% at AGNFR, 49.7% of the bole length of *B. papyrifera* in JENFR remains untapped. Results show that the smaller the dbh the longer the untapped length of the bole because diameters of trees at heights above breast height are likely to be too small to be tapped, while large-dbh trees (dbh ≥30cm) are tapped to 90% of bole length. Yet, this indicates that there is a portion of the bole above the tapped area that retains its full utility value, especially if tapping technique is enhanced to access upper heights while considering tree diameter. Such enhancements could lead to a better management and distribution of tapping locations along the bole without necessarily an increase of their number. Expanding the taping area vertically above old tap holes increases the likelihood of finding new wood and allows more time for wood growth over old holes (Chabot, 2005).

4.3. Number and Characteristics of Tapping Spots

Tapping on all large-dbh trees is made at all directions as recommended. About 3.4% of all tapped trees are first-time tapped that fall in small-dbh (10-14cm) class (N=16), for which the result confirms that tapping is equally made at all directions, too, in contrast to recommendation to restrict their tapping only to east and west directions (Gessmalla et al., 2015). On the contrary, 31.3% of these tapping spots were made in North and South directions.

In JENFR a trend of increased mean number of tapping spots with increasing dbh is noticed (Fig. 4). The number of tapping spots on each tree depends on the diameter of the tree (Tolera et al., 2013), the larger the tree, the more space for tapping wounds (Gonzalez, 2020). The pool computed mean number of tapping spots per tree per year in JENFR doesn't conform to that reported by Ali et al., 2009; Gessmalla et al., 2015; Bongers et al., 2019; Dafa-Alla et al., 2023. Moreover, the mean numbers of spots made on trees of small-, medium- and large-dbh size classes are much higher than the 3, 6 and 9 spots, respectively, recommended by Ali et al. (2009). Tapping has recently intensified since the number of tapping wounds and their dimensions have increased, leading to severe damage to many *B. papyrifera* trees and reduced production of viable seeds (Gonzalez, 2020). Indeed, an optimum tapping intensity needs to be applied to ensure a compromise between tree size, total frankincense yield and impact on the tree (Lemenih & Kassa, 2011).

Findings of previous studies report diverse dimensions of tapping spots made at different locations by use of Mengaf. The initial values of width, length, and depth of tapping spots ranged from 0.4 to 4.0cm, 1.0 to 3.0cm, and 0.5 to 5.0mm, respectively (Ali et al., 2009; Gessmalla et al., 2015; Lemenih & Kassa, 2011; Singh, Katiyar, Ghritlahare & Singh, 2023. The end-of-season dimensions of tapping spots on *B. papyrifera* trees at JENFR recorded maximum values of 6cm, 10cm, and 7mm, respectively. The conventional mechanical techniques used for tapping result in an indeterminate wound of varying depths due to unregulated pressure exerted on the plant stems (Singh et al., 2023). Sustainable harvesting of frankincense trees involves limiting cut depth in the phloem, ensuring not to reach hardwood (Alamri & Al-Shanfari, 2024). However, enhancements in frankincense tapping techniques can be based on an understanding of bark anatomy and distribution and architecture of resin secretory structures (Tolera, 2013, Tolera et al., 2013).

4.4 Frankincense Yield

Tapped trees generally yield significantly more Frankincense than untapped ones (Eshete et al., 2012). Previous research indicates that the average annual frankincense yield per *B. papyrifera* tree can vary greatly. In Sudan, it varies between 186-315g (Gessmalla et al., 2015) and 600g (Nour, 2008) in the Blue Nile region; 328-309g (Ali & Gebauer, 2007), 655-1000g (Ishraga, 2004), 2.2 kg in South Kordofan state, and 2.8kg in Jebel Marra (Khamis, 2001). Compared to other locations, this research produces a relatively lower mean yield of resin because of the short harvesting season and limited number of collections. The discrepancies in frankincense yield among these locations can be attributed to differences in tapping system, population demographics, site conditions, and the varying degrees of influence from natural and anthropogenic factors.

There is a positive correlation between frankincense yield and dbh. Frankincense yield started low then increased steadily to peak at an intermediate dbh (35-39 cm) before declining thereafter (Fig. 5). These results align with previous studies on *B. papyrifera* by Ishraga, 2004; Ali & Gebauer, 2007; Ali et al., 2009 in Kordofan state; Eshete et al., 2012; Cherenet, Katiyar, Ghritlahare & Singh, 2020 in Ethiopea; Alamri & Al-Shanfari, 2024 on *B. sacra* in Oman; which assert that resin yield per tree increases with tree size/dbh. Therefore, it is advisable to limit wounds on smaller trees to a few spots and gradually increase the number of wounds as the tree grows in diameter (Lemenih & Kassa, 2011). This approach can safeguard smaller trees from harm and potentially enhance their growth to a larger and more productive size, particularly considering the slower wound recovery in smaller trees (Eshete et al., 2012).

Previous research reports fluctuations in the number of collections and yield per collection per tree. In the Blue Nile region of Sudan, the resin production is at its peak between the third and sixth collections out of a total of 7 (Gessmalla et al., (2015) and Nour (2008). Ali et al., (2009) reveal that the highest yield occurs during third and fourth ones before declining. Results of this research demonstrates a rising pattern of mean yield from the first to the fifth collection, with the most significant increment observed during the fourth one. The subsequent decrease in frankincense yield could be attributed to the rapid depletion of resin due to intense tapping and collection practices (Cherenet et al., 2020).

5. Conclusion

The tapping system, as one of three characteristics of sustainable harvesting of frankincense, currently practiced at JENFR doesn't conform entirely to established guidelines. In order to ensure sustainability it is imperative to consider the directions of first-time tapping, to reduce untapped bole length, to regulate number of tapping spots, and to improve dimensions of tapping spots. These enhancements require training of tappers to improve tapping skills, improvement of tapping techniques, close monitoring and follow-up on tapping process. The outcomes of this empirical study are not only expected to boost the knowledge about tapping *Boswellia* forests, but also pave the way for more in depth research to standardize harvesting national protocol for frankincense production in Sudan.

Acknowledgements

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