Seasonal dynamics and optimization of tapping methods for sustainable gum harvest in tropical forests of Western Odisha, India

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Research

Abstract

Background: Natural gums are among the most economically significant Non-Timber Forest Products (NTFPs) in India, mostly used as food, fodder, and medicine. In Western Odisha, gum extraction is a key income source for tribal communities. Unsustainable tapping practices severely reduce gum yield and adversely affects tree health. Thus, a sustainable harvesting method is essential for ecological and economic balance.

Methods: We studied twelve gum-producing tree species over three years in Western Odisha. We tested gum yields in different wound types such as size (from 5x5cm to 15x15cm), shape (rectangle, V shape and. Circle hole), location (bottom, middle, or upper trunk), direction (north, south, etc.), and timing (pre-monsoon to winter).

Results: Sterculia urens showed highest gum yielding potential. The most effective method was a 10x10cm^2 rectangular cut on the middle of the trunk, facing east-west, during summer (April-June). This produced 35% more gum than other methods and allowed trees to recover wound. Circular cuts healed 20% slower than rectangular ones. Monsoon tapping reduced yield quality by 40% due to rain wash and moisture contamination, while in winter it reduces by ~55%.

Conclusions: Our findings provide a standardized method for sustainable gum harvesting in terms of wound size, shape, position, directions along with seasonal dynamics. Rectangular wounds (10×10cm^2, mid-trunk, east-west) during summer are optimized condition for sustainable gum yield and tree health. These findings can guide government or NGOs to train Odisha's gum collectors, fostering a sustainable circular economy that boosts rural incomes, secures NTFP-based livelihoods, and safeguards forest health.

Keywords: Non-timber forest products (NTFPs), *Sterculia urens*, Seasonal gum production, Climate-resilient Forest management, Gum tapping, Gum exudation optimization, Forestry resource management, Sustainable forestry,

Background

Forests are a vital component that provides essential resources and ecosystem services that are crucial to maintain ecological balances and support sustainable development. Natural gums are one of the major trades Non-Timber Forest Products (NTFPs) which are directly used as food additives, animal feed, and traditional medicines. Nowadays, gums and resins are used in everything from medicines (thanks to their antiseptic properties) to cosmetics, paints, from food industries to pharmaceuticals and textiles (Nussinovitch, 2009; Prasad *et al.,* 2022) and even waterproofing of ships. It is a major income source for indigenous communities. Livelihood of many rural and tribal communities depends on Non-Timber Forest Products (NTFPs). More than 50 million people rely on NTFPs for food security and income in India (Mahapatra & Tewari, 2005; Sharma *et al.,* 2015, 2024; Lepcha *et al.,* 2022). The Biological Diversity Act, 2002 in India establishes a legal framework to conserve biological resources, promote sustainable utilization of Non-Timber Forest Products (NTFPs), and facilitate equitable benefit-sharing mechanisms with local communities involved in their traditional use and management.

Gums and resins have been traded in India for centuries (Singh *et al.,* 2020) and even show potential in supporting sustainable aquaculture (Paramanik *et al.,* 2023). According to Banjata report by Upadhayay 2006 India trades about 30 different types of gums of which 3% of all traded medicinal plants are gums, and just 2% of gum usage is for medicine. Some gums are in "vulnerable" by the IUCN (Example: *Canarium strictum* and *Sterculia urens*) due to overharvesting or habitat loss. In Odisha gums and resins were under state monopoly until March 2000, when government agencies like TDCC (Tribal Development Cooperative Corporation) and OFDC (Orissa Forest Development Corporation) took over their collection and sale (Rasul *et al.,* 2008). Natural gums are a steady earning source for forest-dependent communities in Western Odisha and central India. Tribal and forest-dwelling communities harvest gums in unsustainable ways which affect tree health and forest homeostasis. During 2006 these products are classified as "specified forest produces or lease bar items " in Odisha which badly impacted the circular economy of local tribal communities (Upadhayay A, 2006).

Forests are the second most important natural resource after agriculture. Wild trees from biodiversity hotspots of tropical forest are major source of natural gums. India's diverse landscapes—from dry deciduous forests to alpine zones—support many gum-yielding species like *Sterculia urens, Boswellia serrata*, and *Anogeissus latifolia*, which are integral to the livelihoods of tribal populations (Dutta *et al.,* 2020; Sahoo *et al.,* 2017; Chitale *et al.,* 2014). According to the ISFR (2021), forests cover of India is nearly 22% of land. Odisha, a biodiversity-rich state in India, is a major player in natural gum production, due to its dense forest cover (39.31% as per ISFR-2019). Western Odisha is rich in gum-yielding trees *like Acacia catechu* (**khair**), *Shorea robusta* (**sal**), *Lannea coromandelica* (**Indian ash tree**), *Mangifera indica* (**mango/Aam**), and *Sterculia urens* (**karaya gum**) (Pradhan *et al.,* 2019; Mohanta *et al.,* 2021). Poor harvesting methods and lack of standardization mean these resources are barely tapped which affect both forests, people and the environment.

Natural gum extraction is done by cutting tree bark to access the inner gum ducts. The gums then naturally ooze from inner tissues and dry into hardened tear shaped droplets (Prasad *et al.,* 2022; Subrahmanyam & Shah, 1988). However, many traditional tapping methods use uncontrolled cuts which damage trees, shortening their lifespan and reducing gum yields over time. Soumya *et al.,* (2019) found that reckless tapping practices have severely impacted *Boswellia serrata* populations in India. To protect these valuable trees sustainable precision tapping practices are needed with respect to wound size, wound direction, wound position which will be controlled minimal cuts to expose gum ducts while ensuring sustainable yield without severe damage to the tree. Yield depends on genetic predispositions of individual trees, their different position and their growing environments (Ali *et al.,* 2009) rather that tapping intensity (Fadl & Gebauer, 2006). Traditional gum tappers utilize unauthenticated and unsustainable tapping methods to collect gums, which is lesser in yield but causes irreparable tree damage or death (Bhattacharya et al., 2003). In our pilot experiment on wound size standardization on *Sterculia urens*, *Boswellia serrata* and *Anogeissus latifolia*, we found a strong association between wound size and gum production. Adam *et al.,* (2009) observed a 60% increase in gum production from *Acacia senegal* wounds facing east-west, with the least output facing north-south.

Natural gum production changes in different seasons due to alter physiology of the trees. Most of the trees of tropical forest shows higher yields during warmer months (Singh *et al.,* 2020). In Western Odisha's tropical forests remain unexplored in development of standardize gum harvesting techniques. Production base of the gum is going down rapidly due to ruthless tapping and unorganized harvesting approach. There's no effort to plant proper tapping and harvesting methods processing methods, understanding seasonal patterns of trees. Research on this article mainly focuses to standardize a balanced solutions for Western Odisha's gum-producing trees, ensuring both productivity and long-term forest sustainability. We experimentally tested over a three-year period to standardize the tapping method and tapping season for sustainable harvest of natural tree gum, which will guide to achieve the most gum output with the least amount of plant damage. Our findings not only safeguard the integrity of forest ecosystems but also contributes to the conservation of wildlife habitats, promoting forest biodiversity and the well-being of value-added trees for NTFP. This also help to increase the circular economy of local livelihood and supporting small-scale enterprises by engaging in sustainable harvesting methods.

Materials and Methods

We started our experiments in January 2021. Tapping optimization was done at different positions and directions for each cut. We ran seven identical trials to check the reproducibility of results. Gum samples were collected in every season (winter, summer, and monsoon). Tree vitality was assessed periodically via bark regeneration rates and wound closure observations.

Study site

Experiments were conducted in forest patches close to Balangir, Odisha. Study was conducted at *Asurdungri* site (Fig.1) located in the Sacred *Mathkhai hill* reserve forest, in the Balangir forest range under Balangir forest division, Balangir, Odisha, India. Geographical location is 20^{0}38’46” N and 83^{0}27’16” E which covers an area of the site is 952,693 m^2 with an average altitude of a minimum 225m to a maximum 624m. from the sea level. Forest is mostly tropical dry deciduous type. For this study 12 different gum-yielding plant species were selected (Table-1) and all the physical aspects were noticed and analyzed continuously for 3 years (2021–2024) along with continuous gum tapping (at an interval of 15 days) in different wound size, different parts and different direction of the plants, collection and measurement of dry gum. In this method for the tapping hammer and chisel of different sizes were used.

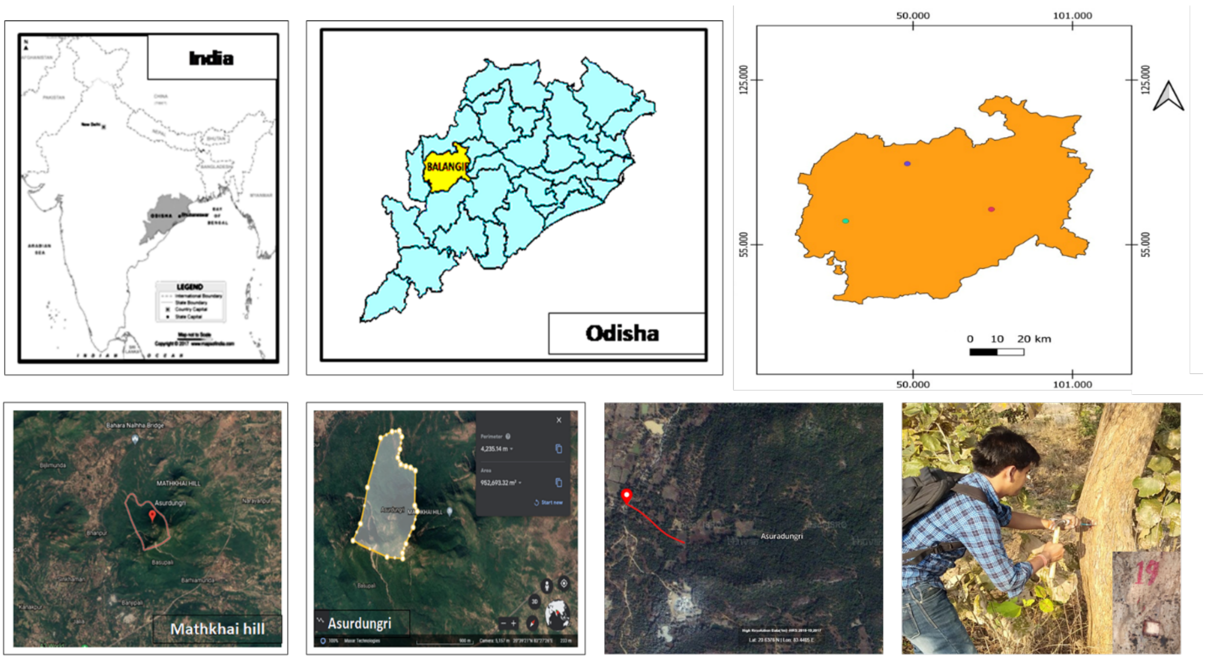

Figure 1. Study site Asurdungri forest at Matkhaihill sacred forest of Balangir forest range, Odisha, India.

Table 1. Twelve gum yielding plants with their family and local names used in this study

Name of the plant	Family	Local name
Sterculia urens Roxb.	Sterculiaceae	**Karaya**
Boswellia serrata Roxb	Burseraceae	**Salai**
Anogeissus latifolia (DC.) Bedd.	Combretaceae	**Dhaura**
Shorea robusta Gaertn.f.	Dipterocarpaceae	**Sal**
Acacia nilotica (L.)Delile	Mimosaceae	**Bamur**
Acacia catechu (L.f.)	Mimosaceae	**Khair**
Lannea coromandelica (Houtt) Merr.	Anacardiaceae	**Joel**
Butea monospema (Lam.) Taub.	Fabaceae	**Palash**
Acacia leucopholea Roxb.	Mimosaceae	**Guhira**
Aegle marmelos (L.) Corr.	Rutaceae	**Bel**
Azadirachta indicia.A.Juss.	Meliaceae	**Neem**
Buchanania lanzan Spreng.	Anacardiaceae	**Chironji**

Tapping Methodology

Mechanical Tapping Technique

Three types of mechanical incisions—square, V-shaped, and hole-shaped—were tested to optimise gum yield during 2021-2024. The details of these methods are outlined below*:*

- ***Rectangular-shaped incision****:* This technique involved making a cut of different size and depth using a carpenter's wood chisel.
- ***V-shaped incision****:* A cut at different length, width and depth, was created near the breast height of trees in the same girth class. This was achieved using a chisel.
- ***Hole-shaped incision****:* In this method cut was made on trees of similar girth using a drill machine.

These methods were designed to test the effectiveness of different shapes of mechanical cuts for gum exudation.

Optimization of Wound size

Upper dead bark was removed from the tree trunk before making incisions as per the hypothesis of gummosis- a natural process where trees produce gum. Wound degrades some inner tissues and creates a small cavity through which converted polysaccharides extruded in the form of gum (Nussinovitch, 2009). Gum was obtained by inflicting artificial harm on the plant in the form of cuts/incisions on the tree trunk (Prasad *et al*., 2016). From each species trees of girth size ≥ 60cm (Vasishth & Guleria 2017) were selected and tagged. On these tagged plants different size of rectangular shaped (2×2, 5×5, 10×10, 15×15 and 20×30 cm^2), V shaped (3×1, 5×2, 5×3, 10×3, 15×5 cm^2) and *Hole-shaped* (0.5, 1.0, 2.0, 2.5, 4.0 cm diameter) wounds were made (Table 2). A particular size of wound was made in 7 replicates of plants. The depth of the wound was half the size of the thickness of the bark in each case. The gums exuded from the different wounds were collected within 3-4 days and after drying they were weighed individually to ascertain the amount of gum produced from different size of wounds made.

Table 2. Details of Experiments for tree tapping for gum yield

Wound Type	Wound Size (cm)	Drilling diameter
Rectangular-shaped incision	2×2, 5×5, 10×10, 15×15 and 20×30	NA
V-shaped incision	3×1, 5×2, 5×3, 10×3, 15×5	NA
Hole-shaped incision	NA	0.5, 1.0, 2.0, 2.5, 4.0 cm

Optimization of Wound position

To optimize the tapping position, selected plants were wounded at three different heights (just above 50cm from the ground, 150cm above the ground and on the upper branches) on the plant stem by following the method of Ali *et al*. (2009). The gum produced from wounds of different positions was collected, dried, and weighed to ascertain the amount of gum produced from the different wound positions.

Optimization of Wound direction

To optimize the right direction for making the wound (size of 10x10cm^2 and at the middle of the stem, predetermined in the wound size experiment) for maximum production of a wound was made for gum extraction in selected plants in four different directions namely East, West, North and South following the method of Adam *et al*. (2009). The gum produced from wounds of different directions was collected, dried, and weighed to ascertain the amount of gum produced from wounds made in different directions.

Optimization of Seasonal impact

To analyze the impact of season on production rate of gum, proper tapping was performed on all the specified twelve trees (Fahn *et al*. 1979; Ballal *et al*., 2005). The secreted gum form each wound of each plant species was collected and the dry weight was measured to understand the seasonal impact on the production rate of gum.

Statistical analysis

The experimental output has been analyzed using the procedure in Microsoft Excel 2019, PREFMAP-Contour plot using XLSTAT-2024 and Central Composition Design (CCD) based Surface plot construction using MINITAB-19. Data represented in figures are mean data of seven replicates. ANOVA were tested for significance test at $p \le 0.05$.

Results and Discussions

Effect of wound shape and size on gum production

The results indicate a significant influence of wound type and size on gum yield, with considerable variation among tree species (Fig. 2). The experimental results demonstrated a strong positive correlation between gum yield and wound size (r= 0.921; P≤ 0.05) in all 12 tree samples. Larger wound sizes generally correlate with higher gum yields, as evidenced by the substantial increase in yield from *Sterculia urens* from 12.503±0.47 to 122.75±4.66 when comparing a 2cm x 2cm to a 20cm x 30cm rectangular cut, representing an increase of 882%. Similarly, V-cuts show a Large increase in yield, with *Sterculia urens* yielding to an increase of 1265% when comparing a 3cm x 1cm cut with a 15cm x 5cm cut. However, *Anogeissus latifolia* shows a decrease of 16.7% in yield with larger rectangular cuts beyond 10cm x 10cm. In *Acacia catechu*, the gum yield ranged from 1.442±0.05 g for a 2cm×2cm rectangular cut to 34.212±1.3 g for a 20cm×30cm rectangular cut. In V-cuts, the yield ranged from 0.771±0.04 g for a 3cm×1cm cut to 22.316±1.29 g for a 15cm×5cm cut. Similarly, for drill holes, the yield increased from 1.7±0.14 g for a 0.5 cm radius hole to 11.55±1.01 g for a 4 cm radius hole. *Boswellia serrata* exhibited similar trends with significant increases in gum yield from 6.663±0.25 g for a 2cm×2cm rectangular cut to 122.75±4.66 g for a 20cm×30cm cut, and 6.362±0.49 g for a 3cm×1cm V-cut to 86.904±4.17 g for a 15cm×5cm cut.

Our findings reveal a positive correlation between species-specific responses and gum yield, aligning with the results reported by Prasad et al. (2022) for *Butea monosperma***.** Similar observations were reported on *Sterculia urens*, *Boswellia serrata* and *Anogeissus latifolia* at Madhya Pradesh and Chhattisgarh (Kala, 2016) and *Commiphora wightii* (Arnott) Bhandari (Saini *et al*., 2018). *Sterculia urens* consistently exhibits the highest yields across various wound types and sizes, indicating a higher potential for gum production compared to other species like *Acacia leucophloea*, which tended to have lower yields. The work of Vasishth (2017) suggests that V-cuts and small drill holes generally result in more controlled and concentrated gum exudation, while larger wounds like rectangular cuts or large drill holes might produce more gum overall but can damage the tree more significantly. Maximum yield was observed with a minimal cut of 10×10 cm^2 rectangular wounds which was selected for optimization of other physical parameters.

Effect of wound direction on gum production

Tapping direction shows a significant variation in gum yield (P< 0.01). Incision towards east-west facing shows a significant increase in gum yield compared to the north-south direction in all the plant species. *S. urens* shows the maximum gum yield of 32.23 gm (Fig.3) in the east-west facing which is 40.80% more than the yield of north-south direction. However, the rate of increase in gum production from east-west to north-south direction of incision was maximum in *B. serrata* (127.89%) followed by *B. lanzan* (110.23%) and *A*. *latifolia* (96.05%) and minimum in *A. nilotica* (25.38%) and *L*. *coromandelica* (28.69%).

Our results support the finding of Adam *et al*., (2009) on *Acacia senegal*. High production of the gum at east-west facing might be due to the high intensity of light and temperature on the trunk faced the east-west direction as compared to the north-south. Our results reveal significant species-specific variations in gum yield responses. These patterns suggest that tapping methods combined with seasonal variation—rather than previous studied isolated factors like light (Raj *et al.,* 2022; Carmona *et al*., 1998) or temperature (Ballal *et al.,* 2005; Das *et al.,* 2014).

Effect of wound position on gum production

Gum exudation significantly varies (P<0.01) according to the wound position relative to ground level. Among the three wound tapping positions of wounds the middle stem position produced a remarkably higher quantity of gum, whereas in the gum production in wounds on the upper branches was the lowest. The gum yield of 12 trees with respect to different wound positions is represented in Fig. 4. A sharp decline (~71%) in gum production on the upper branches was observed in *S*. *urens* compared to the middle branches. *Aegle marmelos* showed the maximum variation in gum production which is 8.14-fold at the middle part compared to the upper branches. *Boswellia serrata* and *Buchanania lanzan* also showed remarkable increase in gum production 8.05 and 4.75 times respectively on wounds on the middle stem compared to the top branches. The least variation in gum production due to wound position was observed in *B. monosperma*, *A*. *latifolia* and *A. leucopholea*.

Similar results of high gum production from the mid stem height have also been reported on *Boswellia papyrifera* (Ali *et al*., 2009). Maximum exudation in middle stem than ground level may be due to more positive xylem pressure on the stem rather than upper branches (Steinberg *et al*., 1990). Sap movement is retarded towards the upper branches (Hacke, 2014) resulting in minimal pressure for exudation. Another reason for the differential exudation at different wound positions may be due to a higher number of gum ducts in the middle and lower trunk compared to the upper branch (Ali *et al*., 2009).

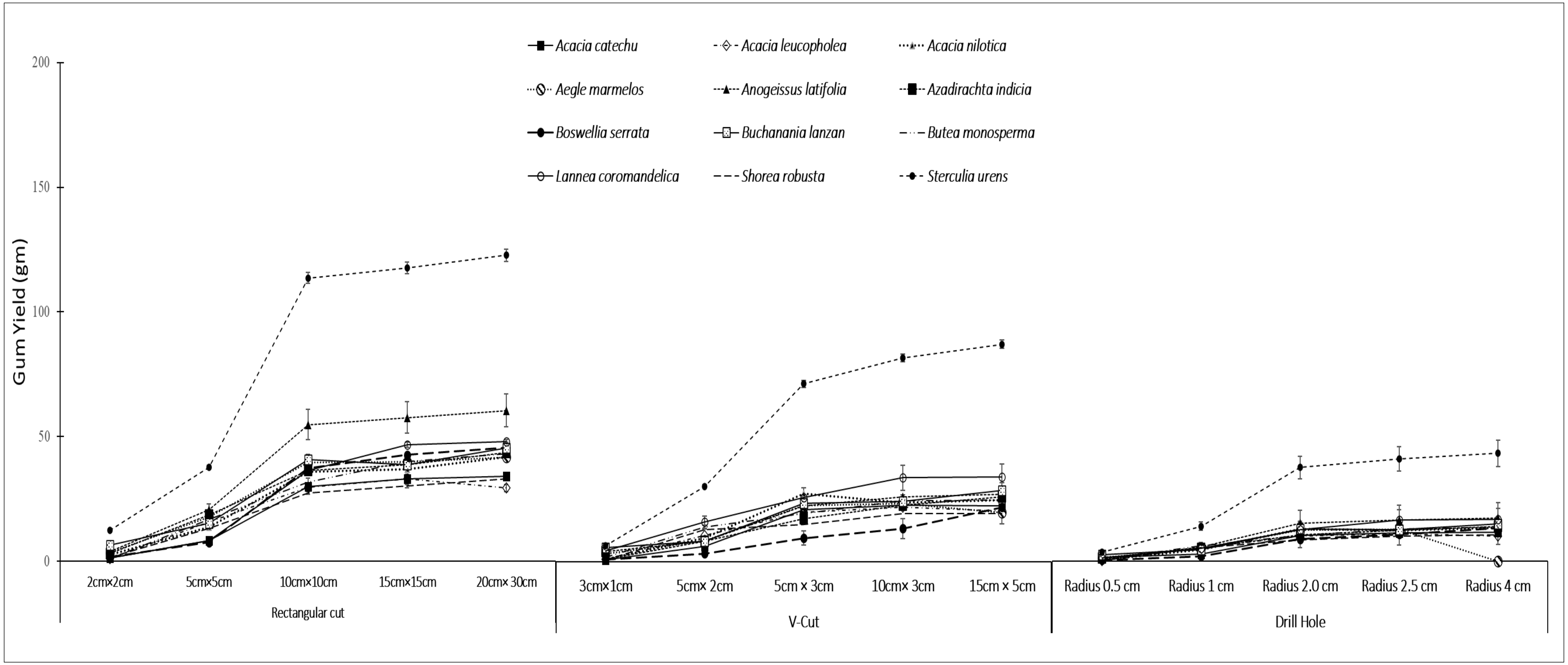

Figure 2. Gum yields from different shape and sizes of wound made on the stem of selected gum yielding plants

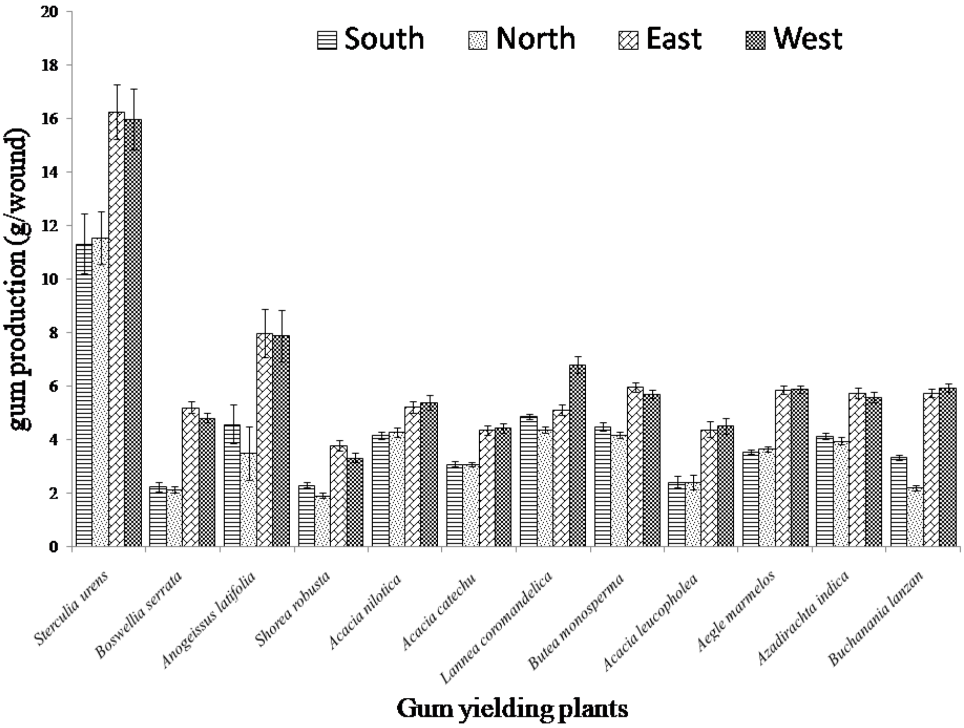

Figure 3. Effect of direction of wound on the yield of gum from gum yielding plants (mean±SD). Data derived from controlled tapping experiments in Western Odisha, India

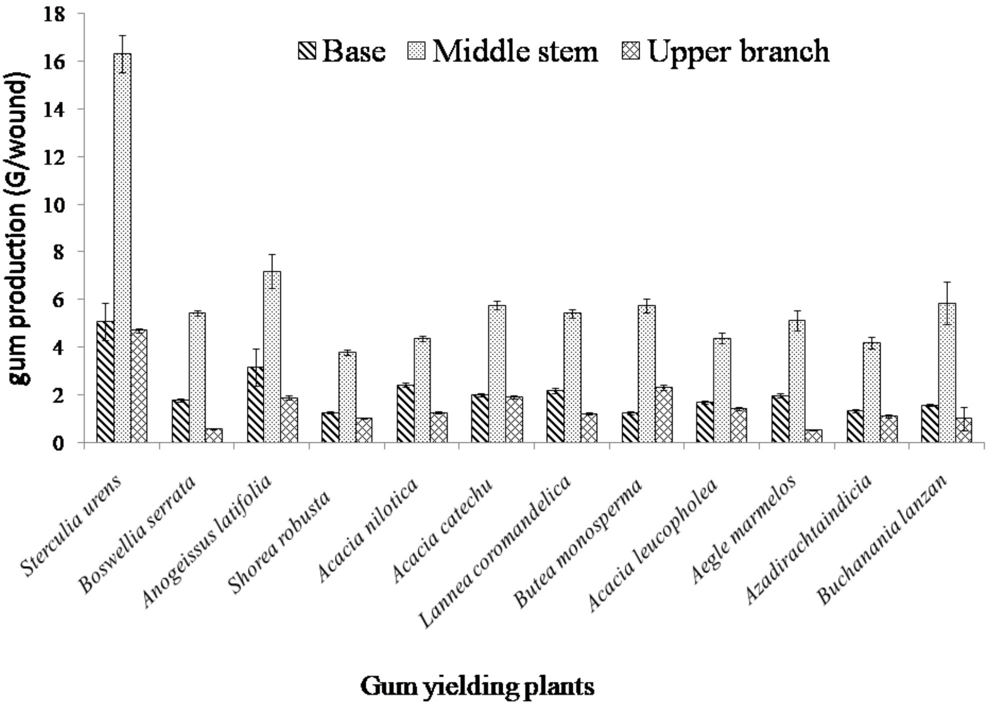

Figure 4. Effect of position of wound on the yield of gum from gum yielding plants. Data reflect three-year field trials comparing species-specific production patterns.

Effect of seasonal variation on gum production

The seasonal variation showed a very prominent effect (P<0.001) on gum production in all the 12 gum-yielding plant varieties. Maximum gum harvest was in June followed by April-May i.e. during the summer season. The highest production during summer season was observed in *S. urens* (11.31±1.32 to 14.97±1.27gm wound^{-1}), *A. latifolia* (9.11±1.92 to 12.1±1.41gm wound^{-1}). *S. robusta* and *B. lanzan* show maximum. yield in May of the summer season (Fig. 5). Gum yield was significantly less during the Monsoon (July-September) and Post-monsoon period (October-November). A positive correlation was recorded between temperature increase from January to June and gum yield ($r = 0.830$; $P<0.05$).

Gum collection was minimal during the rainy season as precipitation washed out the natural exudates. After the post-monsoon period gum production increases and peaks during winter (December, January, and February) and reaches a maximum during summer. A similar observation was reported on higher yields during the dry months of May-June than during any other months due to more cambial activity for gum duct formation leading to a rise in gum production (Fahn *et al*. 1979). Lower temperature may block the gum exudation points that reduce the gum production (Ballal *et al*., 2005; Pio, 1998). Longer photoperiod in summer induced ethylene biosynthesis which in turn increases gum production (Chae and Kieber, 2005). Gum production increases exponentially from March to June followed by slower yield during the rainy season (Fig. 5). Rate of exudation is very much specific to functional trait such as drought, temperature, humidity, etc. (Schenk et al., 2021). Summer is the best season for gum collection because the heat melts frozen tree sap and expansion of internal gases (Tyree & Zimmermann, 2002) which create pressure within wood vessels. This natural pressure pushes more sap out through cuts, resulting in higher yields.

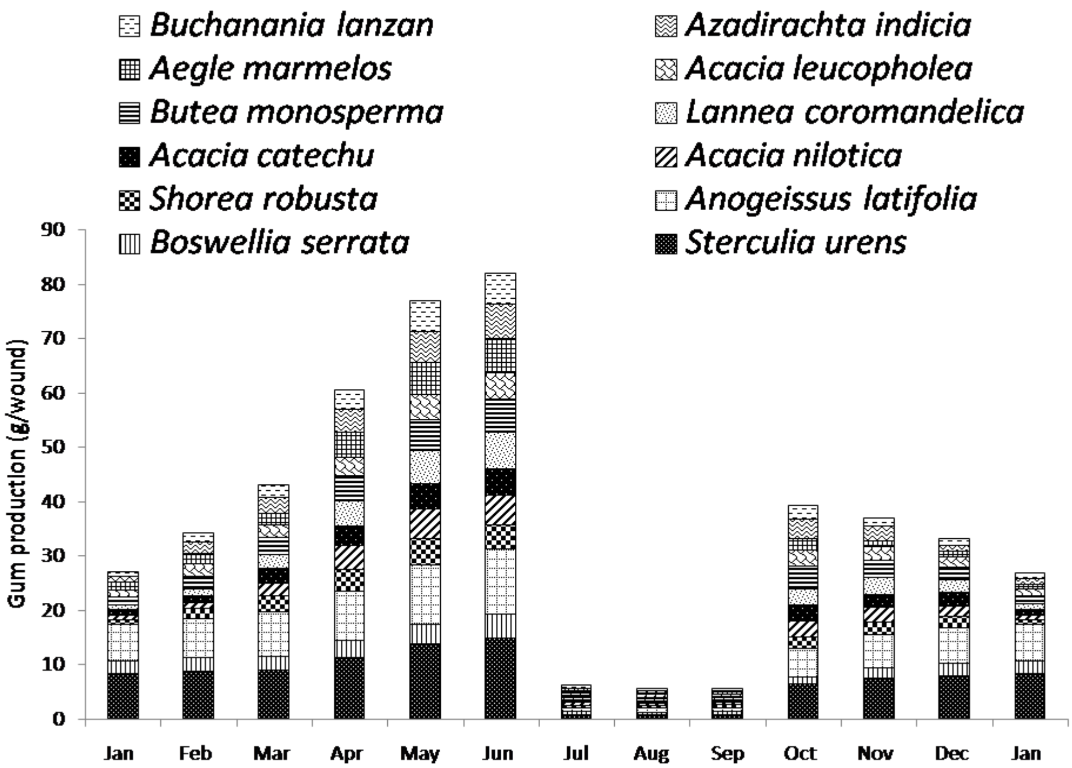

Figure 5. Effect of season on the yield of gum from different gum yielding plants.

Comparative analysis of physical factors for sustainable harvest:

Preference mapping of gum yields was built on the data obtained from multiple domains of experimental conditions to support decision-making for finding the preferable factor towards sustainable harvest of natural gum, the percentage values at each point of the chart was calculated from the fusion plot of PREFMAP and Contour plot (Fig. 7). PREFMAP predictions identify the highest gum production under the following factor conditions (10×10 cm^2 wound size, East-West direction of tapping, Middle stem position of tapping and tapping at in the months of April, May, and June). The Preference Map-Contour plot fusion chart shows the 80%-100% production region of all the 12 plant species at the factors like 10×10 cm^2 wound size, East-West direction of tapping, Middle stem position of tapping, and tapping at in the month of April-May-June. Response surface plot among all the physical parameters was with respect to gum yield represented in Fig. 6. The highest values of gum yield towards the right side of the plot correspond with high values of temperature and optimum humidity of 45% (Fig.6a). The lowest values are in the lower left corner of the plot corresponds with lower values of both temperature and humidity while other factors wound size, direction of wound and position of wound remains constant at 10×10 cm^2, east-west direction and mid stem (150cm from the base) respectively during calculation of fitted response values for gum production. The highest gum yield occurs when wounds are made on the left and right corners (east-west direction) with larger wound sizes (Fig. 6b), while other factors stay at their optimal levels. Figure 6c shows that the middle of the stem produces the most gum, while the base and upper branches (right side) give lower yield.

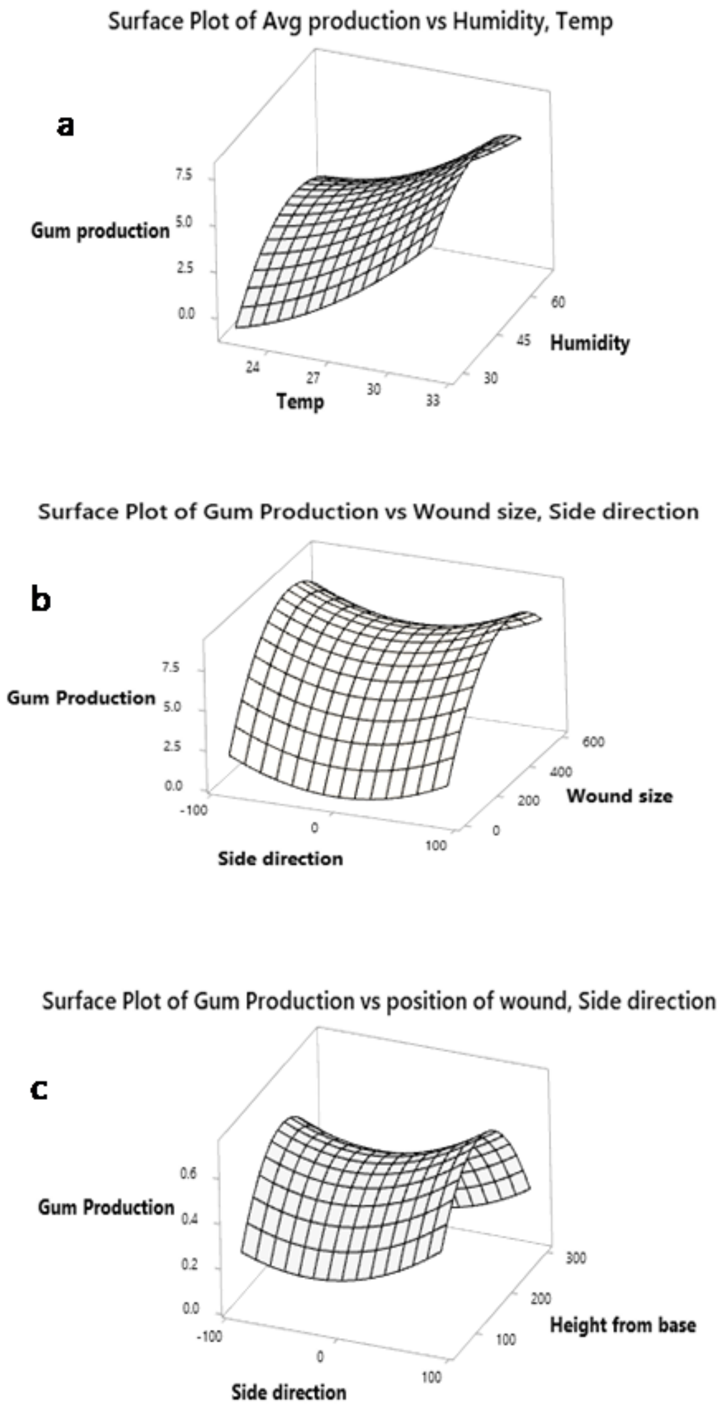

Figure 6. Surface plot among different physical factors along with average gum production in plants a) gum production, temperature and humidity, b) gum production, side direction and wound size, c) gum production, side direction and height from base or position of wound. Data derived from three-year field trials in Western Odisha, India (n=12 species)

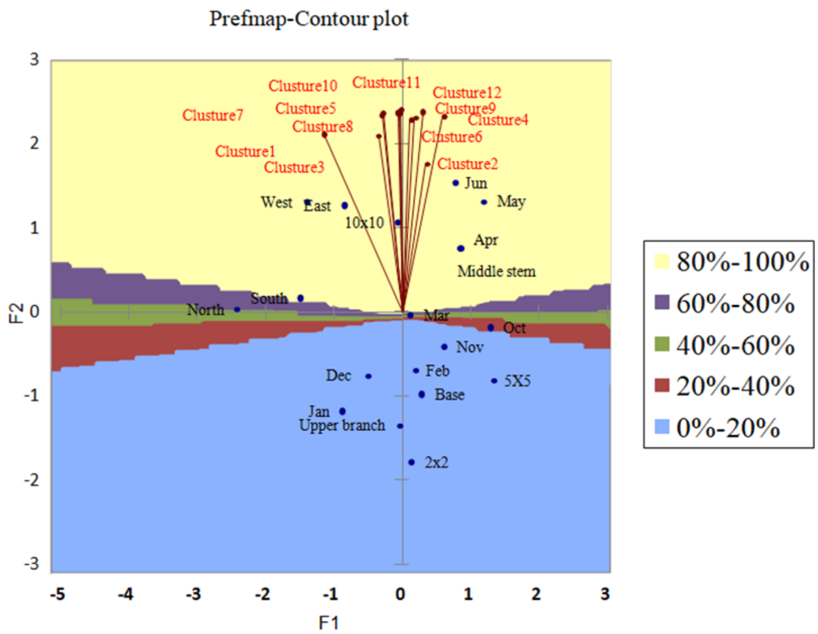

Figure 7. Preference Map-Contour plot fusion chart with production region of twelve plant species (in the regions with blue colour, a low proportion of models give high performance, on the other hand, the region with yellow colour indicates a high proportion of models with high preference).

Conclusion

The influence of physical conditions and seasons on the sustainable collection of natural tree gum was studied. This study provides valuable insights into optimizing gum harvesting from tropical forest trees in Western Odisha, India, focusing on species-specific responses to various tapping parameters. The research demonstrates that gum production is significantly influenced by wound size, wound direction, wound position, and seasonal variations. The results clearly show that the physical elements chosen have a direct influence on the rate of natural gum production from gum-bearing plants. Among the 12 plants, gum yield was maximum in *S. urens.* Alteration in gum production was observed in different plants to different parameters. Wound size increment and production rate are positively correlated to each other. From the contour plot and response surface analysis, 10×10 cm^2 wound size optimizes gum yield. *B. serrata* shows the highest rate of increase in gum production corresponding to increase in wound area. The study also determined that gum yield was significantly higher when incisions were made in the east-west direction, compared to the north-south direction, with the middle of the tree trunk found to be the most suitable position for maximum gum production. The east and west-directed wounds showed the highest production of gum probably due to maximum sunlight exposure to the wounds. The middle of the trunk was found to be a most suitable place for maximum gum production, whereas the least production was at the upper branches which may be due to alteration in xylem pressure and the presence of maximum gum cavities in the mid trunk of the highest girth size. Sustainable production of tropical trees was observed during winter which increases along with the increase in temperature and reaches a maximum during the summer season (April- June). Heavy rain washes out the exudes causing loss in the harvest. So, from this study, it can be concluded that mature plants should be tapped preferably during the summer by a wound size of 10×10cm^2 at the middle stem (Tyree & Zimmermann, 2002)., in the east-west direction. The remaining time of the year is important for wound recovery. The rainy season should be avoided for gum collection as it is the best time for plant recovery and there is a risk of gum loss due to heavy rain. By implementing this standardized method, we can achieve three important goals: 1) consistent production of high-quality gum, 2) reliable seasonal income for local communities, and 3) long-term protection of these valuable trees. When done right, forest can be utilized as steady source of circular economy while keeping the forest healthy for future generations. We recommend integrating these optimized techniques into state forestry training programs to balance economic benefits with tree health.

Declarations

List of abbreviations: NTFP – Non Timber Forest Products; CCD- Central Composite Design; ANOVA, Analysis of Variance

Ethics approval and consent to participate: This study complies with ethical research guidelines for traditional knowledge, including the Nagoya Protocol on access and benefit-sharing. This is the doctoral research topic of Tapas Paramanik at

Centurion University of Technology and Management, Odisha India. Topic is approved by Doctoral Advisory Committee with prior informed consent obtained from Local gum harvester of study sites.

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Competing interests: Not applicable

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