

Comparative Analysis of Morphological Traits and Gum Yield Among Different Provenances of Gum Arabic (*Senegalia senegal*) for Breeding Programs.

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Abstract

This study assessed the effects of provenance, tapping incision, and year of harvest on gum yield and growth traits of *S. senegal* at the Rubber Research Institute of Nigeria, Gum Arabic Sub-Station, Gashua, Yobe State. During the 2012 to 2014 gum collection seasons, the experiment was conducted using a Randomized Complete Block Design (RCBD) with three replications, evaluating 45 trees per *S. senegal* provenance, with 15 trees per replication. Results showed that I7 (seven incisions) produced the highest gum yield (424.42 g/tree/year and 471.53 kg/ha/year), significantly outperforming I3 and I5. Provenance had a significant influence on bark thickness, with trees from Damaturu having the thickest bark (0.75 cm) and the greatest height (453.77 cm). Year also had a strong effect on yield, with the highest yield recorded in 2013 (406.56 g/tree/year), compared to the lower yield in 2014 (167.42 g/tree/year). Significant interactions between provenance and year suggest that the best-performing provenances varied with environmental conditions. These findings indicate that selecting provenances with thicker bark and optimizing tapping intensity can enhance gum production, providing a foundation for breeding programs aimed at improving *S. senegal* yields in semi-arid regions.

Keywords: *Senegalia senegal*, Gum yield, Provenance, Tapping incision, Morphological traits, Breeding programs

INTRODUCTION

Gum arabic, derived from the *Senegalia senegal* (L.) Britton tree, is a highly sought-after natural exudate that finds extensive use in the food, pharmaceutical, and cosmetic industries due to its excellent emulsifying, stabilizing, and thickening properties (Fagg & Allison, 2004). The tree is indigenous to arid and semi-arid regions of sub-Saharan Africa and parts of the Middle East, and its gum serves as a critical source of income and supports local economies (Prasad *et al.*, 2022). The varying ecological conditions in these areas lead to notable differences in the morphological traits and gum yield of *S. senegal* populations, making it essential to conduct comparative studies among different provenances for breeding and enhancement initiatives.

Recognizing the variation among provenances is crucial for breeding programs, as it helps identify superior genotypes that exhibit desirable traits such as high gum yield, stress resilience, and improved growth patterns. Comparative analyses are instrumental in evaluating key morphological features like plant height, stem diameter, and canopy structure, all of which are directly related to the potential for gum production (Chiveu *et al.*, 2008). By selecting provenances with favourable traits, it is possible to achieve higher yields and better-quality gum, ultimately benefiting both producers and consumers while promoting sustainable production practices.

Genetic improvement through the careful selection of superior provenances is key to ensuring sustainable gum arabic production. Fakuta *et al.* (2015) found significant genetic differences among various *S. senegal* provenances in Nigeria, which allows for the selection of high-heritability traits such as stem diameter and bark thickness. This genetic diversity presents an opportunity to enhance breeding programs by concentrating on provenances with superior characteristics, making them ideal for large-scale cultivation.

Morphological traits such as tree height, canopy spread, and stem size are important indicators of a tree's growth performance and its ability to adapt to specific environmental conditions (Fagg & Allison, 2004). For instance, taller trees with wider canopies may have better photosynthetic capacity, which can lead to increased gum production. Additionally, traits like stem diameter play a crucial role in a tree's ability to store and transport nutrients, which in turn affects gum secretion rates (Khasa *et al.*, 2002). Differences in flowering patterns and seed pod characteristics also influence seedling vigour and productivity, helping to identify the best provenances for breeding objectives.

Research on provenance trials has highlighted significant variations in gum yield among different *S. senegal* populations (Fakuta *et al.*, 2015). For example, studies in regions such as Sudan and Nigeria have shown that trees from drier areas tend to produce more gum, likely due to their stress response mechanisms that enhance exudation (Farah *et al.*, 2008). Furthermore, Fakuta *et al.* (2013) pointed out the genetic diversity within *S. senegal* populations in Nigeria, noting significant differences in seedling growth and the relationship to early tapping maturity. These findings emphasize the importance of selecting suitable provenances for specific environments to optimize gum yield in commercial applications. This study was conducted to compare morphological traits and gum yield among various *S. senegal* provenances to identify those with the greatest potential for breeding programs with a view at enhancing gum yield and other desirable traits.

MATERIALS AND METHODS

The study was conducted at the Rubber Research Institute of Nigeria, Gum Arabic Sub-Station, Gashua, located at Latitude 12° 45' 52" N and Longitude 11° 00' 45" E, at an altitude of 360 meters above sea level. Gashua is situated within the Sahel savannah ecological zone of Nigeria.

The experiment was superimposed on a 7-hectare mature gum arabic plantation at the Gum Arabic Sub-Station in Gashua. The plantation was originally established in 2004 with seeds sourced from three natural populations in Damaturu, Borno, and Tolutolu. The seed collection followed the guidelines of Burley and Wood (1987), which standardized the naming of provenances based on locational details, maintaining a minimum distance of 100 meters between sources. To address the genetic diversity of the populations, the most mature and healthy pods were selected from 25 trees within each provenance.

During the 2012 to 2014 gum collection seasons, the experiment followed a Randomized Complete Block Design (RCBD) with three replications, evaluating 45 trees per *S. senegal* provenance, with 15 trees per replication. The trees were assessed for morphological traits and gum yield. Gum tapping was performed using a specialized debarking tool, creating 3 x 15 cm incisions as described by Ojiekpon (2005). The number of incisions per tree was recorded by counting the tapping cuts.

At the beginning of each tapping season, data were collected on morphological traits, including bark thickness (cm), stem diameter (cm) with a Vernier caliper, and tree height (cm), using a tape attached to a long wooden pole. The gum yield per tree was measured by collecting the exudate, drying it at room temperature until it reached 14% moisture content, and weighing it with a high-precision digital scale (Hecky). The first gum collection was carried out 42 days after tapping, with subsequent collections occurring monthly for four months.

The results obtained from the three-year study were subjected to analysis of variance (ANOVA) to evaluate the differences among the provenances, incisions, years and mean separation were all conducted using STAR (Statistics for Agricultural Research) Software, version 2.0.1 (2014), to identify superior provenances based on their gum yield and morphological traits.

RESULTS

Analysis of variance

The means squares for provenance, tapping incision and year of harvest is presented in Table 1. Provenance had significant effects on bark thickness (BTK) at $P \leq 0.01$, stem diameter (SDM) at $P \leq 0.05$, and height at $P \leq 0.01$, but did not significantly affect gum yield. Tapping incision significantly influenced yield per tree per year (g/tree/yr), yield per hectare per year (kg/ha/yr), and number of gum bearing incisions (NGBI), all at $P \leq 0.01$. Year of harvest had significant effects on all gum yield traits ($P \leq 0.01$), as well as on SDM ($P \leq 0.01$) and BTK ($P \leq 0.05$). Among the interactions, Provenance \times Year ($P \times Y$) was significant for yield (g/tree/yr, kg/ha/yr) and NGBI, and Incision \times Year ($I \times Y$) showed significant interaction for NGBI. The three-way interaction ($P \times I \times Y$) and other two-way interactions were not significant for most traits.

Table 1. Mean squares of provenance, tapping incision and year of harvest in *Senegalia senegal*.

| SOV | DF | Yield (g/tree/yr) | NGBI (tree/yr) | Yield (kg/ha/yr) | BTK (cm) | SDM (cm) | Height (cm) |
|----------------|----|----------------------|-------------------|---------------------|-------------|-------------|----------------|
| Replication | 2 | 136081.57** | 0.60 | 167968.34** | 0.027* | 0.33 | 8562.56* |
| Provenance (P) | 2 | 194.73 | 0.38 | 240.36 | 0.150** | 1.99* | 97882.34** |
| Incision (I) | 2 | 245485.82** | 32.81** | 303008.30** | 0.002 | 0.85 | 24037.40 |
| Year (Y) | 2 | 492701.88** | 10.70** | 608152.27** | 0.038* | 5.64** | 6539.11* |
| P * I | 4 | 22479.54 | 0.07 | 27746.97 | 0.007 | 0.99 | 985.74 |
| P * Y | 4 | 55919.08* | 1.48** | 69022.10* | 0.003 | 0.03 | 1390.81 |
| I*Y | 4 | 17113.37 | 1.26** | 21123.39 | 0.001 | 0.65 | 2500.41 |
| P*I*Y | 12 | 7515.96 | 0.21 | 9277.11 | 0.001 | 0.11 | 1183.12 |
| Error | 52 | 23815.28 | 0.29 | 29395.69 | 0.008 | 0.70 | 2448.62 |

*, **: Significant at $P < 0.05$, $P < 0.01$, respectively (F-test)

Means Performance

The mean performance of gum yield and other morphological traits as affected by number of tapping incisions, provenance and year is presented in Table 2. The highest gum yield was observed with seven incisions (I7), producing 424.42 g/tree/yr and 471.53 kg/ha/yr, which was significantly higher than the yields from three (I3) and five (I5) incisions. Interestingly, there were no significant differences in stem diameter and height across the incision levels. Regarding provenance, the Damaturu provenance recorded the highest bark thickness (0.75 cm) and tree height (453.77 cm), outperforming Borno and Tolutolu. Although the differences in gum yield among provenances were not statistically significant, Damaturu consistently showed superior morphological traits. As for the year of harvest, 2013 produced the highest gum yield (406.56 g/tree/yr and 451.69 kg/ha/yr), followed closely by 2012. In contrast, 2014 showed the lowest yield, possibly due to unfavourable weather conditions, which may have impeded gum flow or affected tree physiology. Notably, height measurements in 2013 and 2014 were comparable.

Table 2. Gum yield and other morphological traits of *S. senegal* as affected by number of tapping incision and year of harvest in Gashua.

| Incision | Yield (g/tree/yr) | NGBI (tree/yr) | Yield (kg/ha/yr) | BTK (cm) | SDM (cm) | Height (cm) |
|------------|----------------------|-------------------|---------------------|-------------|-------------|----------------|
| I3 | 235.02b | 1.90c | 261.10b | 0.66 | 8.22 | 369.07b |
| I5 | 310.42b | 2.90b | 344.88b | 0.67 | 8.53 | 368.17b |
| I7 | 424.42a | 4.10a | 471.53a | 0.68 | 8.53 | 420.30a |
| Provenance | | | | | | |
| Damaturu | 322.37 | 3.06 | 358.15 | 0.75a | 8.74a | 453.77a |
| Borno | 321.18 | 2.83 | 356.83 | 0.60c | 8.30ab | 339.04b |
| Tolutolu | 326.31 | 3.01 | 362.53 | 0.65b | 8.24b | 364.73b |
| Year | | | | | | |
| 2012 | 395.87a | 3.23a | 439.81a | 0.63b | 7.90b | 367.89b |
| 2013 | 406.56a | 3.43a | 451.69a | 0.70a | 8.69a | 394.26ab |
| 2014 | 167.42b | 2.25b | 186.01b | 0.68a | 8.69a | 395.39a |
| Mean | 323.28 | 2.97 | 359.17 | 0.67 | 8.43 | 385.85 |
| LSD | 84.28 | 0.29 | 93.64 | 0.05 | 0.46 | 27.03 |
| CV% | 47.74 | 18.19 | 47.74 | 13.43 | 9.93 | 12.82 |

Means followed by the same letters within a column of a treatment group are not significantly different statistically at 5% levels of probability using Fisher LSD.

Table 3. Annual weather data for Gashua, Yobe State, during the experimental period (2012–2014).

| Year | Rainfall (mm) | Mean Temperature (°C) | Mean Evaporation (mm/day) | Mean |
|------|------------------|-----------------------|---------------------------|----------------------|
| | | | | Wind Speed (km/h) |
| 2012 | 656.1 | 38.7 | 28.3 | 115.6 |
| 2013 | 397.1 | 42.0 | 29.4 | 121.7 |
| 2014 | 712.1 | 45.7 | 28.9 | 118.2 |

Source: North East Arid Zone Development Programme (NEAZDP) Hydromet Station.

DISCUSSION

The origin of the *S. senegal* populations plays a vital role in the variation observed in bark thickness and stem diameter. This variability offers opportunities for breeding programs to select genotypes that excel in these traits. The significant differences in tree height among provenances further suggest a strong genetic basis, aligning with prior findings on the role of genetic diversity in adaptability and growth (Lefevre *et al.*, 2004).

Tapping incision had a highly significant impact on yield-related traits ($P \leq 0.01$), including gum yield per tree, yield per hectare, and NGBI. This indicates that increasing the number of incisions during tapping directly affects gum yield, likely due to enhanced exudation in response to increased wounding. Similar patterns have been observed in *Acacia species* (Seif el Din and Zarroug, 1996), supporting the idea that optimizing tapping techniques can boost productivity without damaging the trees.

Yearly environmental variation significantly influenced both yield and morphological traits.

Differences in rainfall and temperature likely account for the observed fluctuations, with 2013 recording the highest yields. This indicates that breeding programs should consider multiple years of data to account for environmental variability when selecting for superior genotypes (Zhang *et al.*, 2024; Payne *et al.*, 2024).

The significant Provenance \times Year ($P \times Y$) interaction reflects the strong influence of annual climatic variation on genetic performance (Table 3). In 2013, low rainfall (397.1 mm) and high temperature (42.0 °C) created drought stress under which only drought-tolerant provenances maintained moderate yields, whereas the wetter conditions of 2014 (712.1 mm) favoured provenances responsive to higher moisture. Similarly, the significant Incision \times Year ($I \times Y$) interaction for NGBI indicates that tapping response was environment dependent; wetter years allowed trees to tolerate more incisions, while in drier years, excessive tapping reduced gum output. These patterns underscore the need to select broadly adapted provenances and to adjust tapping regimes to prevailing conditions in order to sustain gum arabic production.

Among the treatments, I7 (seven incisions) yielded the highest gum output, showing a strong positive relationship between tapping intensity and yield. However, vegetative traits such as stem diameter and height were not negatively impacted, indicating that while yield responds positively to tapping intensity, vegetative growth does not seem to suffer from increased tapping. These findings are consistent with studies on gum producing *Boswellia species* (Rijkers *et al.*, 2006). Thus, selecting genotypes that can tolerate multiple incisions could be an effective breeding strategy for maximizing yield.

Damaturu provenance showed superior bark thickness and tree height, key traits for sustaining higher tapping intensity. Thicker bark is beneficial as it can support multiple incisions without jeopardizing tree health, making Damaturu a suitable candidate for breeding programs focused on yield improvement (Fakuta *et al.*, 2013).

The sharp drop in yield in 2014 despite comparable vegetative growth suggests that unfavourable conditions during that year likely hindered gum production (Abdel Rahman *et al.*, 2006). Therefore, breeding for resilience against adverse weather conditions is essential for improving yield stability over the years.

Breeding Implications

The significant Provenance \times Year and Incision \times Year interactions confirm the presence of strong genotype \times environment effects, indicating that gum yield and tapping response are not stable across environments. For breeders, this emphasizes the need to identify genotypes with broad adaptability that can sustain high yields under both favourable and stressful climatic conditions. At the same time, the observed variation in morphological traits such as bark thickness and stem diameter among provenances reflects a clear genetic basis for these traits, offering selection opportunities for breeding programs. Provenances combining drought tolerance with favourable growth and yield traits should be prioritized, while tapping recommendations should be tailored to seasonal conditions to avoid yield penalties. Overall, these findings highlight the importance of multi-year, multi-environment trials to develop resilient *Senegalia senegal* varieties capable of stable gum production under variable climates.

CONCLUSION AND RECOMMENDATION

To improve gum production of *S. senegal*, breeding programs should focus on selecting provenances with thicker bark and greater resilience to tapping stress, which are essential for maximizing yield in semi-arid regions. Enhancing tapping techniques by increasing the number of incisions can also lead to higher production. Future research should aim to investigate the genetic mechanisms that contribute to the differences in morphological traits and gum yield among provenances, which will help in developing effective breeding strategies.

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