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# Influence of the anatomical structure and wet–dry cycling on the acoustic performance of *Arundo donax* L. (Poaceae) clarinet reeds

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## Abstract

*Arundo donax* L., commonly known as giant reed, has long been used for the production of reeds for woodwind instruments, such as the clarinet, saxophone, oboe, and bassoon. To date, no scientific reports have documented the suitability of giant reed grown in Thailand for woodwind reed manufacturing. In this study, natural giant reed collected from various locations in Northern Thailand was evaluated for clarinet reed manufacturing. After 5 months of seasoning, the anatomical structure, physical characteristics, and the effects of air-drying and repeated wet–dry cycling on the mechanical strength and basic acoustic properties of the giant reed canes were investigated. In addition, the musical performance quality of the reeds was compared with that of traditionally cultivated cane. The results indicated that the anatomical features of Thai giant reed canes, particularly the size of vascular bundles, xylem, and fiber bands, were significantly larger than those of giant reed growing in plantation settings. Air-drying caused no significant changes in the strength properties of Thai giant reed canes. In contrast, wet–dry cycling led to a noticeable improvement in the acoustic performance, with hardness increasing to levels comparable to that of the commercial giant reed canes. These findings indicate that the giant reed grown in Thailand possesses favorable anatomical and acoustic characteristics for clarinet-reed manufacturing, providing a potential cost-effective local alternative to the imported plantation-grown giant reed cane.

**Keywords** *Arundo donax*, Giant reed, Clarinet reed, Reed culm, Vascular bundles, Woodwind instruments

## Introduction

*Arundo donax* L. has long been recognized as a traditional raw material to manufacture vibrating plates, or thin strips of cane known as reeds, used in woodwind instruments, such as the clarinet, saxophone, oboe, and bassoon [1, 2]. When mounted on the mouthpiece, the reed vibrates in response to the blowing pressure generated by the player, producing characteristic tones of the instrument. The unique mechanical and anatomical structure of the giant reed, characterized by high stiffness, elasticity, and low density, makes it ideal for this purpose [3]. The giant reed has been widely cultivated and naturalized in many parts of the world, particularly

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in temperate and subtropical zones, including France, Spain, and Italy, which serve as the main regions for the commercial reed cultivation for woodwind instrument manufacturing [4, 5]. However, in tropical regions, including Southeast Asia, imported reeds often exhibit considerable variability in performance and are sold at relatively high prices. These performance inconsistencies, together with the associated import costs, highlight the need to identify alternative locally available materials that can provide comparable or improved quality at a lower cost. Assessing the quality of reed cane requires a broad understanding of the plant's botany and physiology, as well as its anatomical, mechanical, and acoustic properties, all of which are influenced by cultivation, harvesting, and curing practices [2, 6]. The giant reed is a tall, perennial grass species characterized by hollow culms with diameters of approximately 2–3 cm and heights ranging from 4 to 6 m. The culm is segmented by nodes occurring approximately every 20 cm, which provide structural reinforcement. In cross section, the culm wall comprises of a thin hypodermal sclerenchymatous layer and a thicker parenchymatous region with vascular bundles encased in lignified bundle sheaths that provide longitudinal reinforcement to the stem [7–9]. Previous studies have reported that the reed quality is significantly correlated with anatomical features, such as size of the parenchyma cells, diameter of the vascular bundles and their surrounding fiber rings, and the presence of twisted or broken fiber rings [2]. These anatomical parameters directly affect the mechanical stiffness, elasticity, and acoustic response of the reed [1]. Despite the widespread availability of giant reed in Thailand, there is limited scientific information on the suitability of Thai-grown giant reed as a raw material for woodwind instruments. Since the environmental factors such as soil composition, rainfall, and temperature strongly influence cane anatomy and density, region-specific studies are essential for determining its potential use [10].

Establishing a local supply of reed cane would reduce reliance on imports while promoting domestic reed production, supporting the growth of small business, and fostering innovation in musical instrument manufacturing in Thailand. Beyond its role in the woodwind reed production, giant reed has also gaining attention as a sustainable and multipurpose biomaterial. Owing to its rapid growth rate, high cellulose content, and robust mechanical strength, this species has been investigated for applications in bioenergy production, composite reinforcement, pulp and paper manufacturing, and eco-friendly building materials [11–14].

The present study aims to evaluate the potential of Thai-grown giant reed as an alternative source of raw material for clarinet reeds. This research aims to evaluate whether the giant reed cultivated in Thailand exhibits suitable characteristics for clarinet reed production. Giant reeds were collected from three localities in Northern Thailand and compared with commercial plantation reeds. The effects of air-drying and repeated wet–dry cycling on the anatomical structure, mechanical strength, and basic acoustic properties were investigated. The study would provide baseline data that could support future startup ventures or investment in the Thai reed industry.

## Materials and methods

### Preparation of raw material

Mature culms of giant reed were collected from three distinct sites in Northern Thailand representing different growth environments: Pang Mapha district, Mae Hong Son Province (PM); Ban Sob O, Chiang Dao district, Chiang Mai province (CDA); and Ban Mae To, Chiang Dao district, Chiang Mai province (CDB) (Fig. 1). The canes were harvested during the dry season to minimize any variations in moisture content. At each site, fully matured culms were cut approximately 10 cm above the ground level using clean, sharp blades to prevent structural damage. After harvesting, the whole culms were cut into two parts and air-dried indoors in a laboratory setting for further experimentation. For comparative purposes, commercially cultivated giant reed cane was obtained as raw culm sections from Rigotti (Anduze, France), a professional supplier of plantation-grown *Arundo donax* cane for woodwind instrument reed manufacturing. The commercial cane was processed into clarinet reeds following the same preparation procedure described in Sect. "Clarinet reeds preparation", to ensure a consistent and unbiased comparison with the Thai-grown samples.

### Air–dry and wet–dry of the specimens

After air-drying for 5 months, the giant reed culms were cut into internodal sections for specimen preparation. A total of 80 specimens were prepared, each measuring approximately 70 mm (longitudinal, L) × 25–30 mm (tangential, T) × 4 mm (radial, R). Ten representative specimens were selected to undergo a wet–dry cycling treatment, while the remaining specimens were retained as the air-dried control group. The wet–dry cycling treatment was introduced based on evidence that repeated hydration and drying induces structural relaxation and mechanical improvement in *Arundo donax* reed material [22]. In this process, the specimens were immersed in distilled water for 15 min, and the cycle was repeated 14 times to simulate repeated exposure to moisture. Following this, the specimens were soaked continuously in water for 12 h and then air-dried under controlled ambient conditions until mass equilibrium was reached. All




**Fig. 1** Photos of three giant reed sites in Northern Thailand; **a** PM = Pang Mapha district, Mae Hong Son province, **b** CDA = Ban Sop O, Chiang Dao district, Chiang Mai province, **c** CDB = Ban Mae To, Chiang Dao district, Chiang Mai province

prepared specimens were stored in sealed plastic containers for the analyses of their anatomical and mechanical properties, and acoustic quality related to reed performance. It should be noted that the 5-month air-drying period represents a preliminary investigation and longer seasoning durations comparable to commercial practice are recommended for future studies.

### Investigation of the physical properties

Five specimens for each internode were determined as follows:

*Moisture content (MC):* The initial mass of each specimen was measured, after which the specimens were oven-dried at 103 ± 2 °C until constant mass (24 h). The oven-dry mass was then recorded, and the moisture content (MC) was calculated using the following equation:

$$MC(\%) = \frac{(m_1 - m_0)}{m_0} \times 100, \quad (1)$$

where $m_1$ is the mass before drying (g) and $m_0$ is the mass after oven drying (g).

*Specific gravity (SG):* The same specimens used for moisture content determination were used for SG measurement. The SG of each specimen was calculated using Eq. (2), based on the oven-dry mass and the corresponding specimen volume:

$$SG = \frac{m_0}{V}, \quad (2)$$

where $m_0$ is the mass of the specimens after oven drying (g), and $V$ is the specimen's volume before drying ($cm^3$).

Note that these specimens were sacrificed after physical property measurements (see Fig. 2).

### Microstructure of reed culms

Reed culm blocks, approximately 20 mm in length, were prepared from mature giant reed culms deemed suitable for clarinet reed production. The general distribution of vascular bundles in the culm cross section was first examined using a stereo microscope (Stemi 508, Zeiss, Germany) equipped with a digital camera (Axiocam 208 Color, Zeiss, Germany). Transverse sections of the culm with a thickness between 3 and 4 mm were obtained using a sliding microtome (SM2000R, Leica, Germany). The resulting sections were stained with safranin, dehydrated through a graded ethanol series, and mounted on glass slides for microscopic examination. Microstructures were subsequently observed using a light microscope

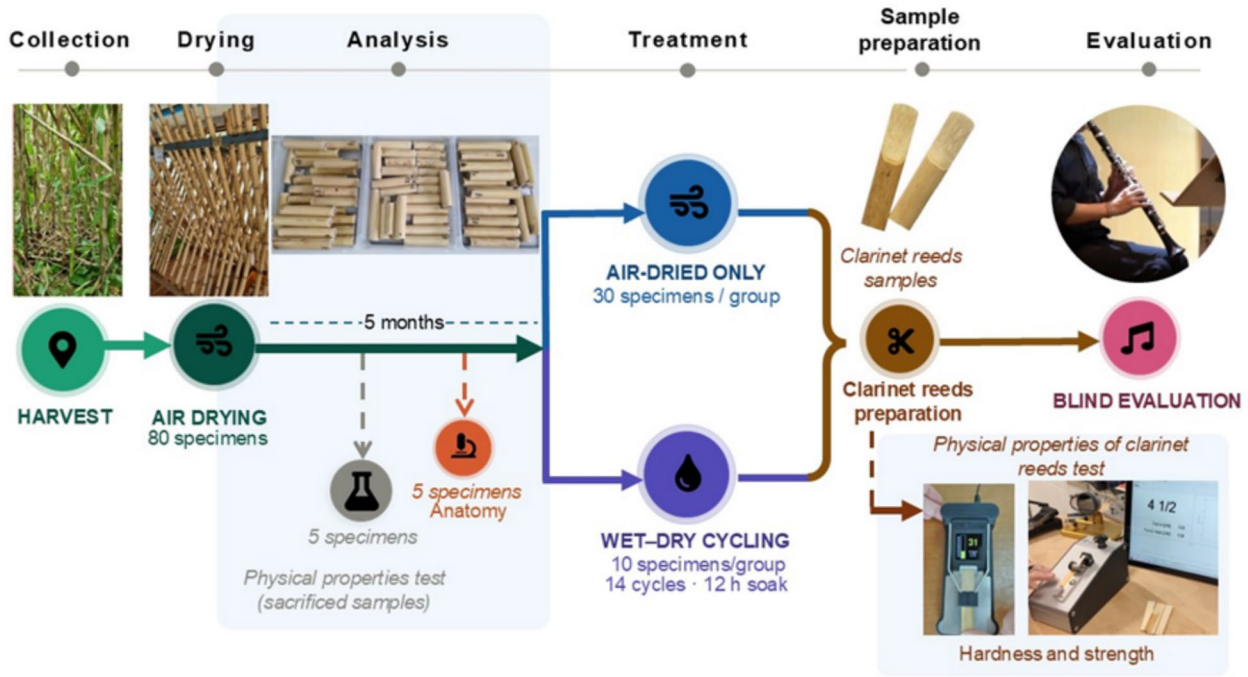



**Fig. 2** Overview of sample preparation and experimental workflow

(Axioscope 7, Zeiss, Germany) equipped with a digital camera (Axiocam 506, Zeiss, Germany).

### Clarinet reeds preparation

The preparation of clarinet reeds followed conventional manufacturing procedures adapted for experimental evaluation. The initially harvested giant reed culms were split longitudinally into four equal sectors to obtain straight and defect-free blanks suitable for reed production. Each culm was separated carefully along the fiber direction to preserve its structural integrity and minimize damage to the vascular tissues. The inner portions of the culm were then cut into rectangular plates measuring approximately 70 mm (L) × 25–30 mm (T) × 4 mm (R), as illustrated in Fig. 3. These plates served as the reed blanks for further processing. Subsequently, the blanks were progressively planned and shaped to the desired reed geometry following the clarinet-reed manufacturing standards. Clarinet reeds were produced from giant reeds sourced from the three locations (PM, CDA, and CDB) for a comparative evaluation.

### Evaluation of musical quality

To assess the musical performance quality of the clarinet reeds, a blind evaluation was conducted by three professional clarinetists. For each giant reed sources (PM, CDA, and CDB), five reeds representing both air-dried and wet–dry cycled conditions were prepared. To eliminate bias, each musician evaluated the reeds independently and without prior knowledge of their origin or treatment. The performers rated each reed on five criteria related to the overall playability and tonal response: Excellence (5), Good (4), Fair (3), Needs Improvement (2), and Poor (1). Mean score of the three evaluators was used to represent the musical quality index for each sample group.

## Results and discussion

### Appearance and physical characteristics of reed culms

The external morphology of giant reed culms collected from different locations in Northern Thailand is shown in Fig. 4. After the removal of leaf sheaths and surface cleaning, the fresh culms exhibited a yellowish-green color with a smooth outer surface and a slightly curved or bent shape in some internodes (Fig. 4a). The culms displayed distinct nodes and internodes, similar to those reported for giant reed cultivated in the Mediterranean regions. Following air-drying under ambient conditions, the color of the culm changed from bright green to a light yellow or beige tone, resembling the hue of an eggshell (Fig. 4b). However, several dried culms had surface blemishes, including brown to dark spots and streaks, which are likely associated with localized fungal infection or enzymatic oxidation originating from partially decomposed leaf sheath residue. In some samples, structural deformations were observed. These included radial cracks visible at the cross section (Fig. 4c) and

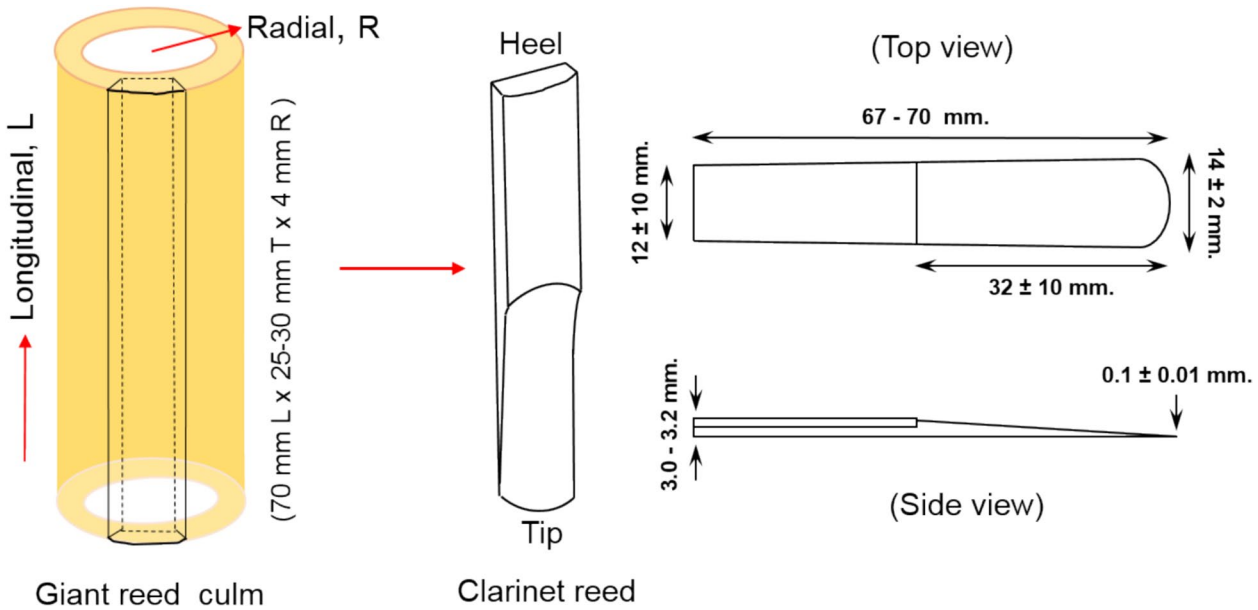



**Fig. 3** Diagram illustrating the part of giant reed cane selected for image analysis with a cross section through the heel of clarinet reed




**Fig. 4** Morphological characteristics and common defects observed in giant reed culms collected from various locations in Thailand: **a** fresh culms, **b** air-dried culms showing discoloration marks (red arrows), **c** transverse sections indicating radial cracks at the culm edges (red arrows), and **d** longitudinal collapse or groove deformation along the internode surface (depicted in the red box)

longitudinal groove-like collapses along the internode length (Fig. 4d). The collapse typically initiated near the node region and extended 1–2 cm along the culm before diminishing. Such deformation is presumed to result from uneven shrinkage and internal stress during moisture loss after harvesting.

The basic density and moisture content of giant reed culms from Thailand were compared with those of a commercial reed sample (Fig. 5). The results show clear regional variations, reflecting differences in growing conditions, culm maturity, and post-harvest moisture fluctuations. The basic density values of Thai reeds ranged from approximately 355 to 440 kg/m$^3$, which are comparable to or slightly lower than those of the commercial sample (395 kg/m$^3$). Among the Thai sources, the culms sampled from PM exhibited the highest density, followed by those from CDA and CDB. Higher basic density reflects a greater volume fraction of bundle sheaths, which has been shown to be directly associated with increased storage modulus and stiffness of reed material [24]. Similar anatomical observations were reported by Karczewski et al. (2025) who noted that denser giant reed culms tend to produce reeds with higher vibrational stability and improved tonal consistency. Slightly lower densities in CDA and CDB samples may be related to environmental conditions, such as higher humidity or faster growth rates, which promote parenchyma development over fiber thickening [10].

Maintaining moderate and uniform moisture content is critical for reed stability, as excessive moisture can lead to dimensional changes and tonal inconsistency [6]. The moisture content of air-dried Thai culms ranged between 51 and 60%, which was similar to the equilibrium moisture levels of the commercial reeds. Among the regional samples, PM recorded the lowest average moisture content, which indicates a more compact cellular structure with reduced porosity, limiting the penetration of moisture into the culm wall. As a result, these denser reeds exhibit lower moisture absorption capacity, while the CDA and CDB samples retained slightly higher moisture.

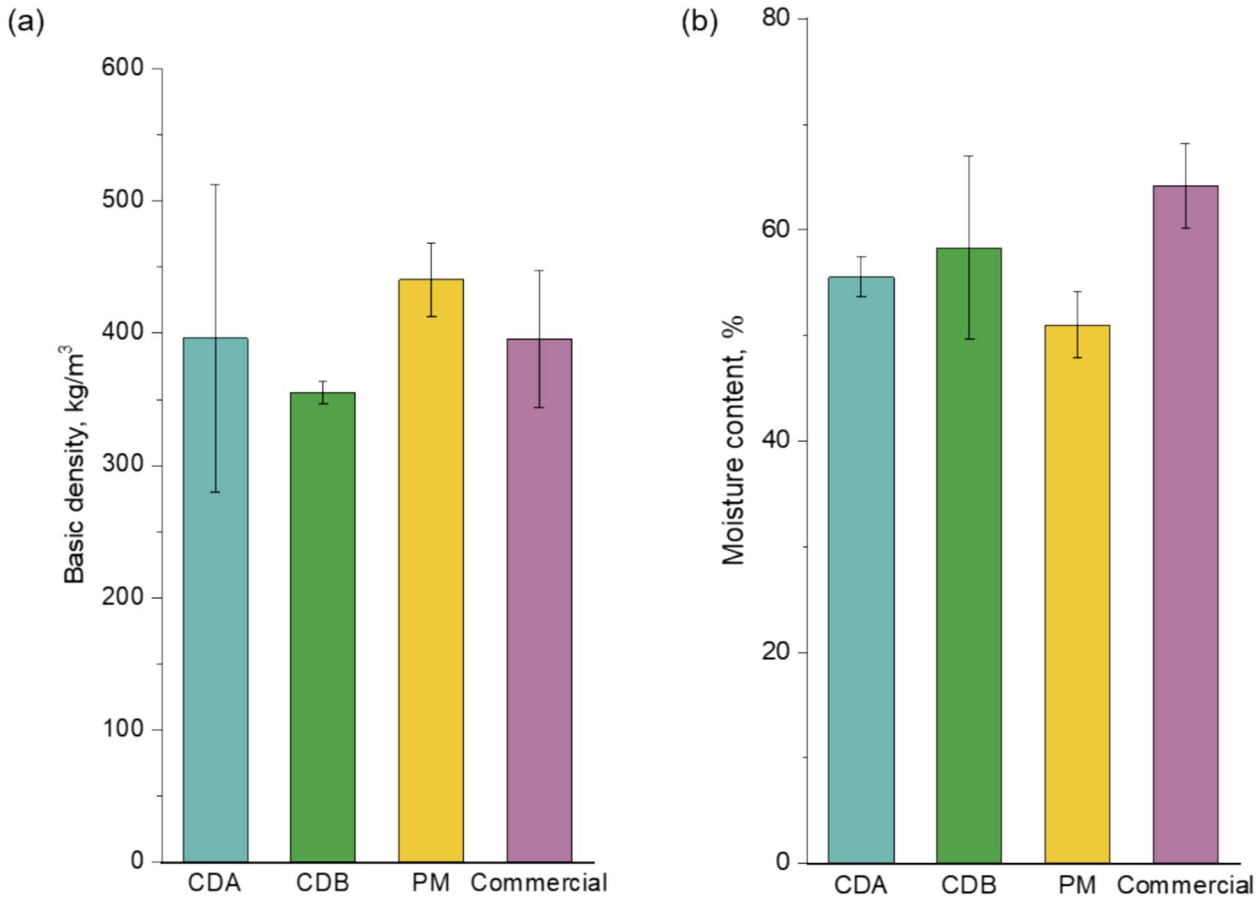



**Fig. 5** Basic density (**a**) and moisture content (**b**) of the giant reed culms collected from three locations in Northern Thailand, Ban Mae To (CDA), Ban Sop O (CDB), and Pang Mapha (PM). Error bars indicate standard deviations of triplicate measurements

#### Microscopic characteristic of reed culms

The anatomical structure of the cross section of a giant reed culm is illustrated in Fig. 6. The culm exhibits a nearly circular shape with a large central cavity, and a cylindrical wall of vascular and parenchymatous tissues. Scattered vascular bundles are embedded within the parenchymatous ground tissue, showing a gradual increase in bundle density from the inner to outer portion of the culm wall. Each vascular bundle consists of phloem (P), two metaxylem vessels (MV), fibrous strands (FS), and ground parenchyma (GP) surrounding the conducting tissues. This arrangement corresponds well with the typical monocotyledonous structure described in previous studies on giant reed and other related species [2, 3, 6, 15, 16].

Microscopic observations indicated that the fibers are concentrated around the protoxylem, phloem, and metaxylem, contributing to mechanical reinforcement of the culm. Numerous thick-walled fibers were also observed within the fiber strand area of each vascular bundle. The bundle size decreased from the inner to the outer culm wall, where bundles near the epidermis were denser and more compactly arranged (Fig. 7). This radial gradient in bundle size and density is consistent with previous findings suggesting that the outer culm region provides a greater rigidity and tensile strength, an important characteristic for wind instrument reed [1, 6]. When comparing the Thai-grown reeds with the commercial samples, significant anatomical differences were observed. The vascular bundles of commercial reeds were generally smaller and more densely distributed, whereas the reeds sampled from PM, CDA, and CDB exhibited larger vascular bundles with well-developed peripheral sclerenchyma and smaller parenchyma cells, possessing thicker, more lignified walls. Similar structural trends have been reported by Brancheriau et al. (2006), Cheng et al. (2010) and Kolesik (1998), who found that the quality of a woodwind reed is influenced by bundle size and the cell wall of the sclerenchyma sheath [2, 17, 18]. The thick wall observed in the Thai samples may contribute to their increased hardness and acoustic stability after moisture cycling [3, 6]. These observations support the

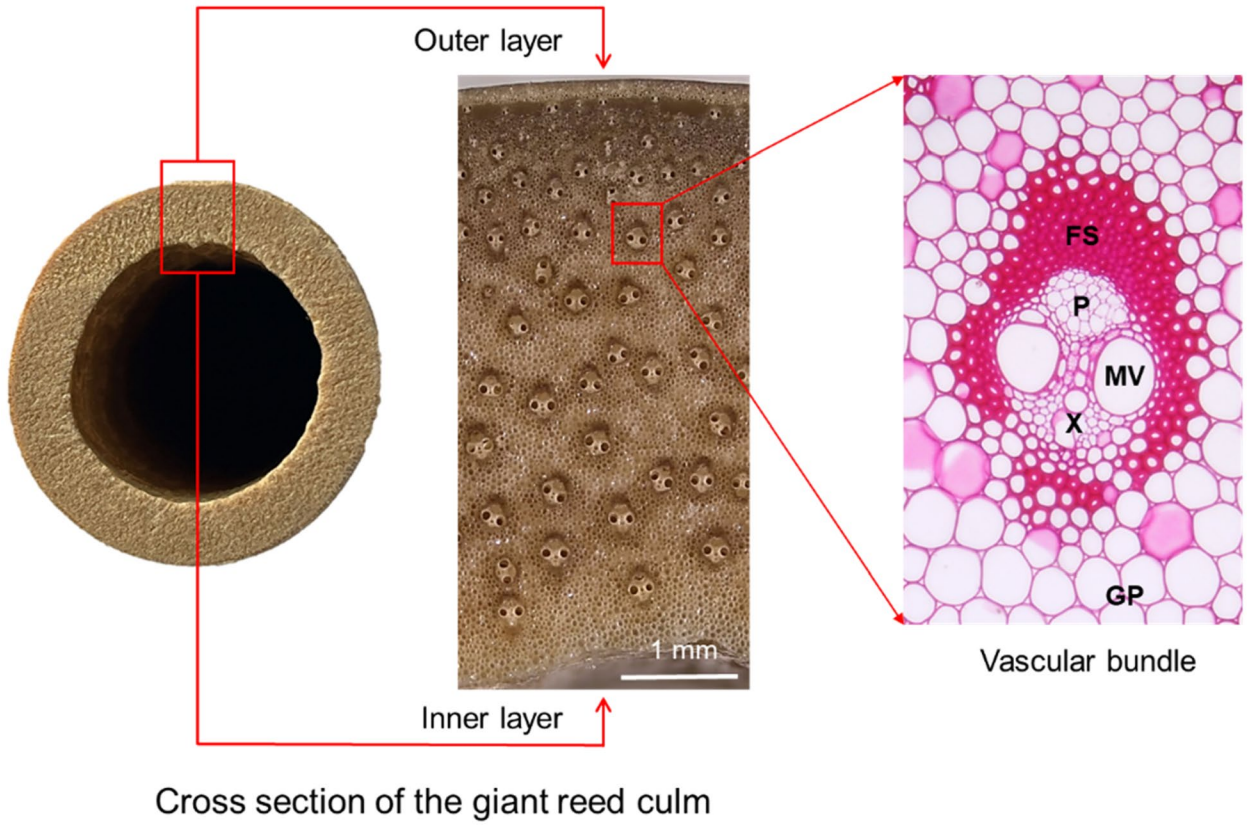



**Fig. 6** Microstructure of giant reed for **a** culm circular cross section and distribution of vascular bundles from the outer to the inner surface **b** vascular bundle; FS = Fiber strand, MV = Metaxylem vessel, P = Phloem, GP = Ground Parenchyma, and X = protoxylem

notion that anatomical variability among growth regions is influenced by environmental factors, such as soil composition, temperature, and water availability, affecting tissue vascular differentiation and cell wall formation [10, 19, 20]. The study indicates that giant reed culms from PM, CDA, and CDB possess anatomical characteristics suitable for clarinet reed production, with structural variations that may directly affect their mechanical and acoustic performance.

#### Musical quality of the Clarinet reeds specimens

The musical performance of clarinet reeds produced from giant reed grown in Northern Thailand was assessed by three professional clarinetists using a blind evaluation method (Table 1). The evaluation considered three attributes, which was in terms of range, dynamic response, and articulation that were graded on a five-point scale (5 = Excellence, 1 = Poor). Clarinet reeds made from the three locations (CDA, CDB, and PM) were compared with a commercial control under both air-dried (5 months) and wet–dry cycled conditions. In the air-dried group, the commercial reeds received the highest scores across all parameters, indicating their superior playability and tonal stability. Among the Thai samples after air-drying 5 months, reeds from PM achieved the best ratings (range = 3.67; dynamic = 3.56; articulation = 3.73), followed by CDB and CDA. These results suggest that the PM reeds possessed a more balanced vibration behavior and sound response, likely related to their denser and more homogeneous culm structure.

After wet–dry cycling, the musical performance of the Thai reeds improved markedly. Reeds from CDA and CDB showed increased ratings in every category, reflecting enhanced elasticity and surface compliance, following repeated moisture exposure. The reeds demonstrated the highest quality among the Thai sources, with musical quality scores approaching those of the commercial reeds, particularly in range (3.99) and articulation (3.95). The practical experience among clarinetists supports the idea that controlled moisture exposure improves reed performance. Many musicians routinely soak or re-moisten reeds before playing and report enhanced flexibility and tonal response after repeated wet–dry cycles. Similar discussions can be found in online clarinet forums, where players describe that a gentle soaking or alternating wet and dry conditions help stabilize the reed behavior

during performance [21]. Such observations are consistent with the structural adjustments observed in this study through the mechanisms proposed [22, 23]. Importantly, the observed improvement in musical quality can be directly linked to changes in reed hardness induced by wet–dry cycling. As shown in Table 2, the hardness of the CDA reeds increased markedly after cycling, with values rising from 0.45 to 0.30, while CDB reeds exhibited a

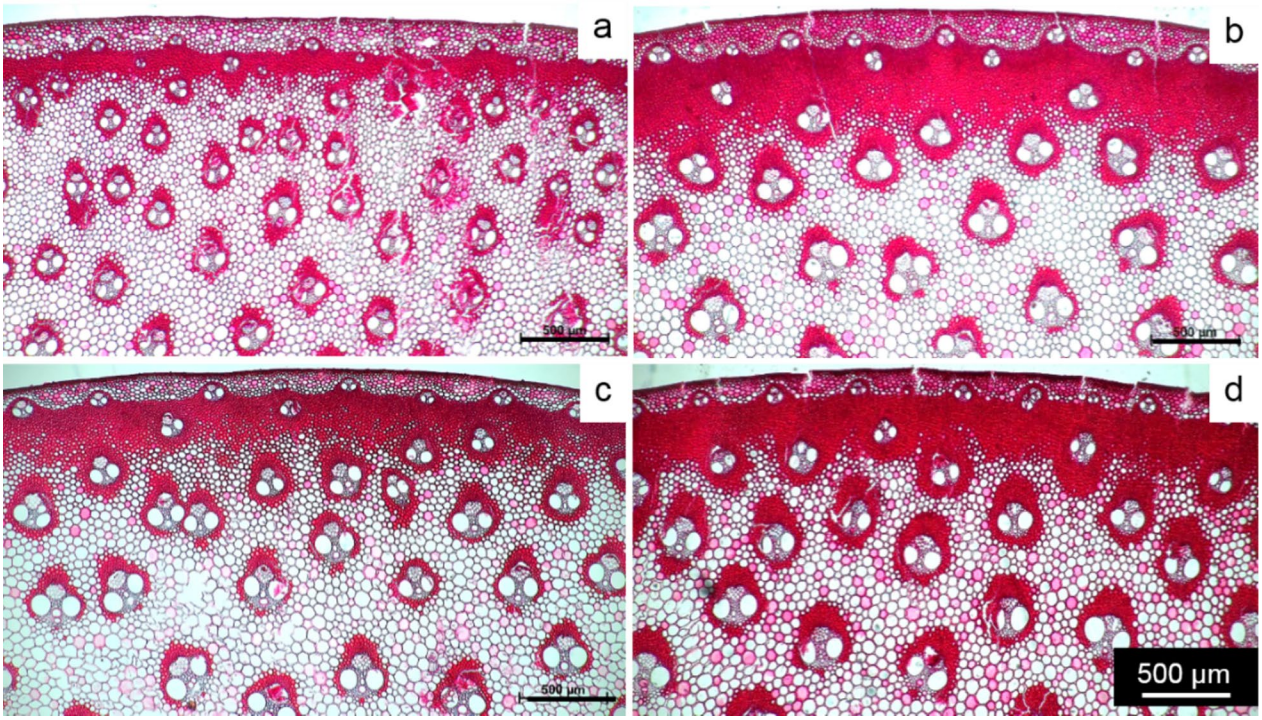



**Fig. 7** Cross section and distribution of the vascular bundles from the outer to the inner surface of four giant reed culm, **a** Commercial, **b** PM = Pang Mapha district, Mae Hong Son province, **c** CDA = Ban Sop O, Chiang Dao district, Chiang Mai province, **d** CDB = Ban Mae To, Chiang Dao district, Chiang Mai province

**Table 1** Comparison of the musical quality of commercial clarinet reeds relative to those sampled from three locations in Thailand on a scale of 5 based on the overall playability and tonal response

| Quality | Air–dry 5 months | | | | Wet–dry 5 months | | | |
|---|---|---|---|---|---|---|---|---|
| | Commercial | CDA | CDB | PM | Commercial | CDA | CDB | PM |
| Range | 4.45 | 2.26 | 2.97 | 3.67 | 4.61 | 3.99 | 3.70 | 3.61 |
| Dynamic | 4.52 | 2.28 | 2.90 | 3.56 | 4.48 | 4.04 | 3.55 | 3.53 |
| Articulation | 4.47 | 2.16 | 2.85 | 3.73 | 4.25 | 3.95 | 3.56 | 3.56 |

*Excellence (5) Good (4) Fair (3) Improvement (2) Poor (1)

**Table 2** Comparison of the hardness and strength of clarinet reeds relative to those sampled from three locations in Thailand and commercial

| Clarinet reeds quality | | Air–dry 5 months | | | Wet–dry 5 months | | |
|---|---|---|---|---|---|---|---|
| | Commercial | CDA | CDB | PM | CDA | CDB | PM |
| Hardness (mm) | 0.23 (0.03) | 0.45 (0.11) | 0.37 (0.05) | 0.35 (0.05) | 0.30 (0.07) | 0.33 (0.09) | 0.31 (0.07) |
| Strength (cN) | 170.06 (11.76) | 169.60 (12.65) | 168.73 (11.63) | 170.00 (13.49) | 169.80 (12.70) | 169.13 (12.36) | 169.53 (12.42) |

Values in parentheses are standard deviations (n = 5)

moderate increase from 0.37 to 0.33. A similar trend was observed for the commercial reeds (PM), where hardness improved from 0.35 to 0.31. These results indicate that repeated moisture exposure led to a more uniform and mechanically optimized reed structure.

The increase in hardness indicates cell wall rearrangement and partial densification, leading to enhanced stiffness while retaining adequate flexibility. This optimized viscoelastic balance allows more controlled reed vibration under airflow, improving articulation, tonal stability, and dynamic range. Consequently, reeds with greater hardness stabilization after wet–dry cycling, particularly CDA and CDB, exhibited musical performance comparable to commercial reeds.

In general, the thickness of tip of the clarinet reed is at most 100 µm (Fig. 8). Figure 9 shows stereomicroscopic images of the tip region of clarinet reeds made from giant reed collected from the different locations and treatments. This region of the reed is critical as it is the primary vibration zone which directly influences tone production and playing response. Distinct differences in the fiber orientation and surface texture were observed between reeds of good and poor musical quality, as evaluated by the professional clarinetists. In the high-quality reeds, the xylem and phloem fiber appeared fine, evenly arranged, and well-aligned along the longitudinal direction. The surface was relatively smooth with uniform light reflection, indicating a compact and homogeneous tissue structure favorable for consistent vibration.

In contrast, the low-quality reeds exhibited coarser, thicker, and irregular fiber patterns, often with darker streaks or uneven fiber spacing. These structural irregularities can disrupt vibration uniformity and lead to a less responsive tone and reduced articulation control. Such microstructural differences correspond well with the musicians' performance feedback, suggesting that the

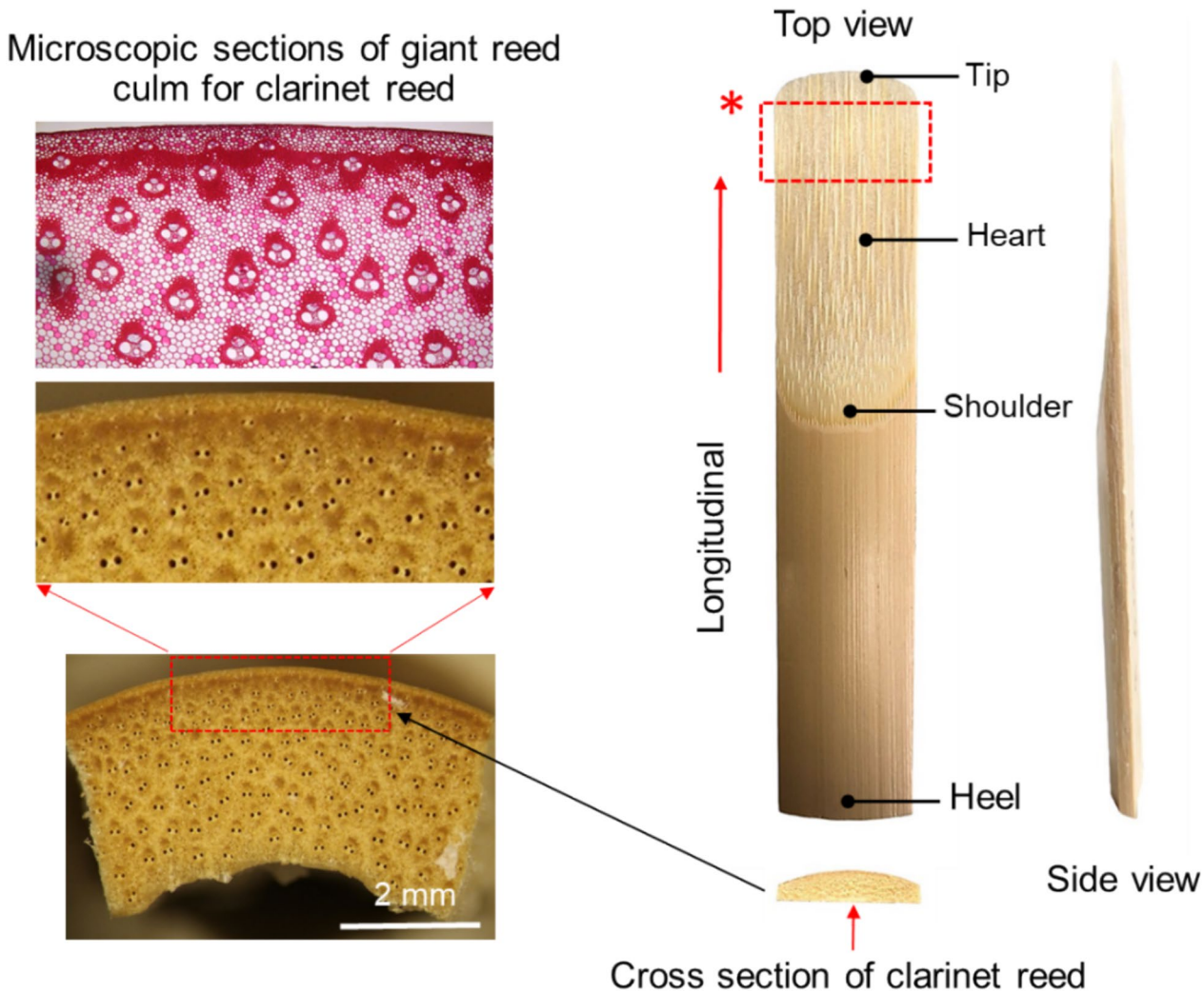



**Fig. 8** Microscopic sections of giant reed culm for clarinet reed production; * the tip zone of clarinet reed for anatomical observation

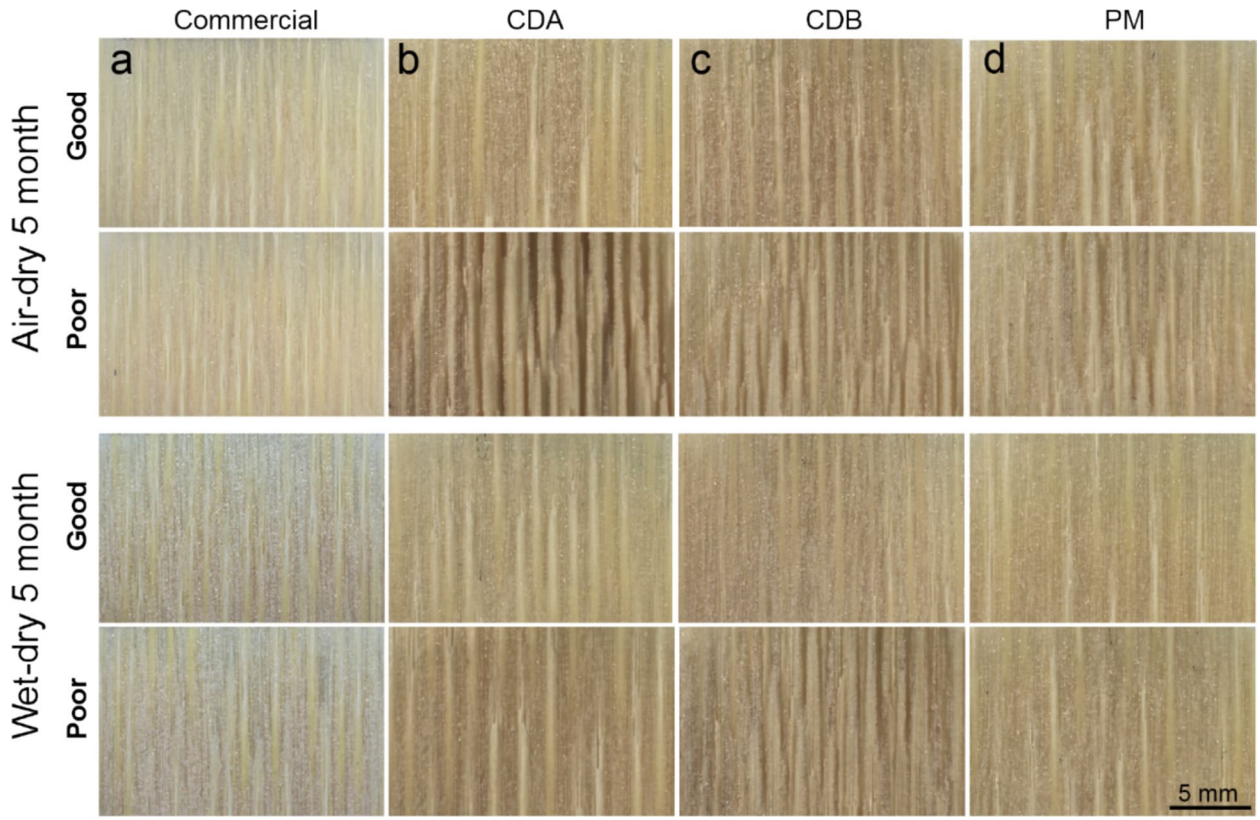



**Fig. 9** Stereomicroscopic images of the tip region of clarinet reeds made from giant reed from different sources and treatments: **a** commercial reeds, **b** CDA = Ban Sop O, Chiang Dao district, Chiang Mai province, **c** CDB = Ban Mae To, Chiang Dao district, Chiang Mai province, and **d** PM = Pang Mapha district, Mae Hong Son province. Images correspond to the vibration zone of the reed tip. Fine and evenly aligned fibers are visible in the higher-quality samples, while coarse and thick fibers are characteristic of the lower-quality reeds, as evaluated by professional clarinetists

visual appearance of fiber alignment can be used as an indicator of reed quality. Furthermore, the differences in fiber thickness and smoothness can often be detected by simple visual inspection or tactile examination, providing a practical tool for musicians when selecting reeds. Reeds with a smoother and finer grain typically yield more stable resonance, while those with coarse fibers tend to produce harsher or unstable tones.

These results confirm a strong relationship between the anatomical organization of the cane tissue and musical behavior of the reed. The findings are consistent with the observations of Kolesik et al. (1998) and Bucur (2019), who reported that the microstructural uniformity of vascular and fibrous tissues directly influenced the reed flexibility and tonal stability [2, 3]. The present study demonstrates that even subtle anatomical variations such as fiber thickness and bundle alignment can be detected visually or by touch, serving as reliable indicators of reed quality. This relationship provides not only a scientific explanation for the musicians' evaluations but also a practical guideline for reed selection and quality control in future Thai reed-manufacturing efforts.

## Conclusions

This study explored the potential of using giant reed obtained from Northern Thailand as an alternative raw material for making woodwind instrument reed. From an anatomical and physical point of view, the results compare the quality of reeds from plantation canes specially cultivated for manufacturing reeds for clarinets, with the reeds made from giant reed growing in three locations of Thailand. Microscopic analysis showed that the vascular bundles, xylem vessels, and fiber bands of the Thai reeds were larger than those of the commercial reed, while the outer sclerenchyma layers were well-developed with thickened and lignified cell walls. These characteristics indicate a robust structure capable of withstanding variations in vibration and humidity during reed performance. The wet–dry cycling treatment positively influenced the acoustic behavior of the Thai reeds, leading to improved hardness, tonal response, and stability, which was comparable to that of the commercial reeds. This improvement is likely due to the internal structural relaxation and redistribution of the bound moisture within the cell wall during repeated hydration and drying. Among the

studied sources, canes sampled from Ban Sop O (CDA) had the most balanced combination of density, stiffness, and acoustic responsiveness, resulting in the highest musical quality as evaluated by professional clarinetists. The stereomicroscopic images of the tip region of clarinet reeds indicated fine and evenly aligned fiber structures as a characteristic of reeds considered to be of high quality, whereas coarse and irregular fibers corresponded to poorer tonal performance. The findings demonstrate that giant reed cultivated in Northern Thailand possesses favorable structural and acoustic characteristics suitable for clarinet reed production. The scientific foundation provided in the study can be used for developing a local reed-manufacturing industry, reducing dependence on imported cane, and promoting small-scale enterprise and innovation within the Thailand's musical instrument sector.

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**Author contributions**
Buapan Puangsin: data curation, investigation, writing—original draft, writing—review and editing, visualization, validation, supervision, project administration, funding acquisition, and conceptualization. Piyawan Yimlamai: methodology, investigation, data curation, formal analysis, and writing—review and editing. Korawit Chitbanyong: methodology, investigation, data curation, and writing—review and editing. Chatchai Ngernsaengsaruay: methodology, resources, and writing—review and editing. Sawitree Pisutpiched: writing—review and editing. Nattapon Banjatammanon: methodology and writing—review and editing. Chunwang Yang: methodology and investigation. Somwang Khantayanuwong: writing—review and editing, validation, and supervision.

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**Availability of data and materials**
All data and materials in this study are included in this published article.

## Declarations

**Ethics approval and consent to participate**
Nat applicable.

**Consent for publication**
All the authors gave consent for publication.

**Competing interest**
The authors declare that they have no competing interest.

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