

Original Research Article

Adaptation and Growth Performance of Different Introduced Bamboo Species in Central Tigray, Northern Ethiopia

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ABSTRACT

Bamboo is a giant bushy grass and typically a faster growing perennial than any other tree species and it starts to give utility within three or four years of planting time, except bearing seeds. The study was conducted on four bamboo species (*Bambusa bambos*, *Phyllostachus edulis*, *Yushania alpina*, and *Bambusa vulgaris*) to evaluate their adaptability potential and growth performance at Laelay Maichew district, central zone of Tigray, Ethiopia. The design of the experiment was carried out using a randomized complete block design (RCBD) with three replications. The distance between the experimental plots and blocks was 2 m and 3 m, respectively, and the spacing between bamboo seedlings in the plot was 2 m x 2 m, with 4 bamboo seedlings per plot. A total of 48 bamboo seedlings were planted in the experimental site. The growth parameters; including survival rate, new emerging shoot, internode length, number of nodes, culm height, culm diameter, and root culm diameter were measured and recorded. The collected data were statistically analyzed using one-way analysis of variance (ANOVA) between treatments following the post hoc test of Tukey at $P < 0.05$ using SPSS for Windows version 20. The results revealed that *Bambusa bambos* has a better survival percentage (100%), followed by *Bambusa vulgaris* (58.3%), *Yushania alpina* (41.67%), and *Phyllostachus edulis* (0%). The growth parameters: new emerging shoot (culm), collar diameter, diameter at stump height, and diameter at breast height of *Bambusa bambos* were significantly higher than those of *Yushania alpina* and *Bambusa vulgaris* ($P = 0.001$). However, for similar parameters, *Yushania alpina* showed non-significant variation with *Bambusa vulgaris* (at $P > 0.05$). The mean heights between treatments (*Bambusa bambos* (5.1 m), *Yushania alpina* (4.5 m), and *Bambusa vulgaris* (4.2 m)) were observed statistically non-significantly different (at $P = 0.26$). The other growth parameters were: the mean value of total internode length (TIL) and middle internode length (ML) of *Bambusa bambos* was significantly higher than that of *Bambusa vulgaris* (at $P < 0.05$). The study revealed that, among the four bamboo species, *Bambusa bambos* showed higher growth performance and adaptability potential, followed by *Yushania alpina* and *Bambusa vulgaris*. As a result, the best-performing introduced bamboo species (*Bambusa bambos*) could be promoted to end users in related agro-ecological areas for various benefits. Further studies should be recommended on the adaptability of the introduced bamboo species in other agro-ecologies.

Key words: Bamboo species, Adaptation, Growth performance, Introduced

1. INTRODUCTION

Bamboo is an exceptional group of giant bushy grasses in tropical and subtropical ecology in which the woody culms arise from underground rhizomes [1]. Bamboo is also a perennial, woody-stemmed grass and usually hollow and semi-solid to solid culms with distinct nodes and internodes, rhizomes and branches. They are shrubs, which have a tree like habit, their culms are erect and sometimes climbing. They are part of the grass subfamily called Bambusoideae, which is in the Gramineae family [2].

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Bamboo is one of the fastest-growing plants in the world with rapid regeneration potential, which offers significant advantages over the other plant species [3]. Environmentally, bamboo plants have tree-like

functions [4], and it is a multi-purpose plant [5], which can provide an opportunity for watershed development and the restoration of degraded areas through mitigation of soil erosion [3]. There are almost over 10,000 verified bamboo uses and products [6]. These include timber products, cloth, plastic mixes, food, energy, health, and cosmetics. It has also a proven eventuality in the restoration of degraded lands, watershed protection, and climate change mitigation and adaptation strategy [7].

Worldwide there are more than 1,500 bamboo species covering more than 14 million ha of land in the tropical, subtropical and temperate regions of all continents except Antarctica and Europe [8, 9]. With respect to the entire bamboo community, China is the first country having the highest diversity of bamboo species (800 bamboo species) and followed by India with 160 species [10]. Africa has more than 43 bamboo species occurring naturally or introduced [11]. The two bamboo species are indigenous to Ethiopia: *Oxytenanthera abyssinica* (A. Richard) (lowland bamboo) and *Oldeania alpina* (K. Schum.) (highland bamboo). The pure natural bamboo forest in Ethiopia is the largest in Africa, having area coverage of over 1 million ha [12], which is about 7% of the world total and 67% of the African bamboo forest area [13].

Even though Ethiopia is one of the most endowed countries having huge coverage of bamboo resource in Africa, but the country has limited genetic diversity, with only two bamboo species, *O. alpina* (highland bamboo) and *O. abyssinica* (lowland bamboo), which are confined to specific agro ecological areas [14]. With the two bamboo species it has a significant challenge to secure a constant supply of bamboo raw material for industries, enterprises and regional and/or national handicrafts. Even though, bamboo species play a crucial role in addressing climate change mitigation, reduce land degradation and creating economic opportunities for a substantial segment of the population, it is deteriorating in an alarming rate due to overexploitation, shifting cultivation and extensive forest fire. This all problems with bamboo species in Ethiopia and similarly in Tigray is due to the low diversity and availability of bamboo species/bamboo resource.

Therefore, this study was designed to introduce and evaluate the adaptability potential and growth performance of introduced bamboo species in Tigray. This will increase the genetic diversity of bamboo species, create income diversify and promote sustainable land management practices. The objective of this study was to introduce and evaluate the adaptability and growth performance of the new introduced exotic bamboo species in central zone of Tigray.

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2. MATERIALS & METHODS

2.1. Description of the study area

The experiment was carried out in Laelay Maichew district (figure 1). The district is geographically located between 13° 36" North latitude and 39° 36" East longitude. Laelay Maichew district is located about 245 km North West of Mekelle city, the regional capital of Tigray. The district has an altitude which ranges from 2050 to 2200 m a.s.l. with two agro-ecological zones, namely, lowland and mid-highland. The mean annual temperature of the district ranges from 12°C to 28°C and the annual rainfall varies between 500-900 mm [15].

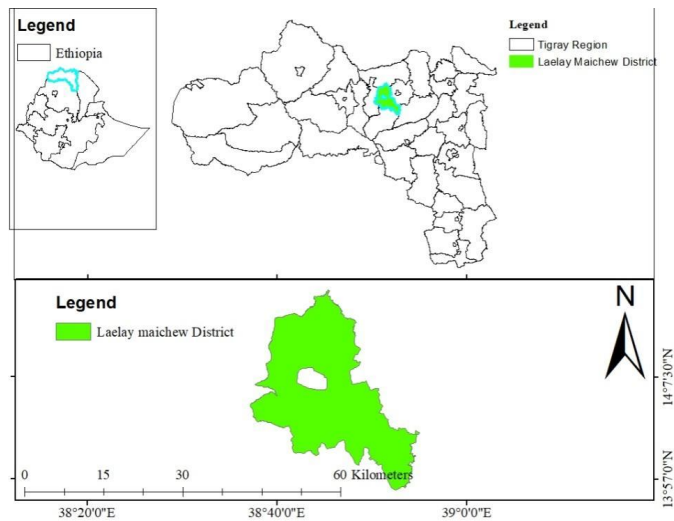


Figure 1: Map of the study area

2.2. Treatments and Experimental Design

In this study, the design of the experiment is carried out using randomized complete block design (RCBD) with three replications. The experiment contains 12 experimental units: four treatments (*Bambusa bambos*, *Phyllostachus edulis*, *Yushania alpina* and *Bambusa vulgaris*), replicated three times. The distance between the experimental plots and blocks were 2 m and 3 m, respectively. The spacing between the bamboo seedlings within the plots was 2 m X 2 m. The total number of bamboo seedlings in the experiment is 48 seedlings (4 seedlings per plot x 3 replications x 4 species). All the bamboo species were obtained from forestry research center of Addis Ababa, and planted in July, 2020. The exotics bamboo species were originally comes from China and planted at field to evaluate their adaptability and growth performance of the species.

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2.3. Data collection

The experimental trial was conducted from 2020 to 2024 at Laelay Maichew district to evaluate their adaptability potential and growth performance of bamboo species to select the best performed bamboo species. The collected data were: survival rate, number of culm (emerging shoots), culm height, root collar diameter, diameter at stump height (DSH), diameter at breast height (DBH), internodes length, number of nodes, lower internodes length, middle internodes length and upper internodes length.

2.4. Data Analysis

Prior to the analysis of the treatments effects, assumptions of normality data on the adaptability and growth Parameters of the introduced bamboo species were checked using the Shapiro – Wilk test. The collected data were statically analyzed using one - way analysis of variance (ANOVA) between treatments following the post hock test of Tukey at $P < 0.05$ using SPSS for windows version 20.

3. RESULTS AND DISCUSSIONS

3.1. Survival rate (%)

The survival rate (%) of the introduced bamboo species in the experimental trial showed that *Bambussa bambos* has the highest survival rate (100%) followed by *Bambussa vulgaris* (58.3%), *Yushania alpina* (41.67%) as illustrated in Figure 2. However, *Phyllostachus edulis* was not adaptable, which showed the least survival rate with (0%). The result of this study indicated that, the agro ecology of Laelay Maichew district is suitable to *Bambussa bambos*, *Bambussa vulgaris* and *Yushania alpina*. Similar result was reported for *Bambusa bambos* by [16], which have survived 100%, [17] account for 94% and [18] *B. bambos* survived (91.67%) in south eastern zone of Tigray. The best survived introduced bamboo species in this study was not attacked by pests and diseases. However, *Phyllostachus edulis*, exhibited 0% survival rate was highly attacked by pests and disease. Pests and diseases might be other factors for the low survival rate of bamboo species in Laelay Maichew. According to its nature *Phyllostachus edulis* is well adapted in humid tropics and temperate zone with enough water availability and more humidity zone [19, 20]. This might be one factor for the least adapted bamboo species in the experimental trial in semi-arid zone. This result agrees with [18] that *Phyllostachus edulis* survived (16.6%) which was the least survived in south eastern zone of Tigray.

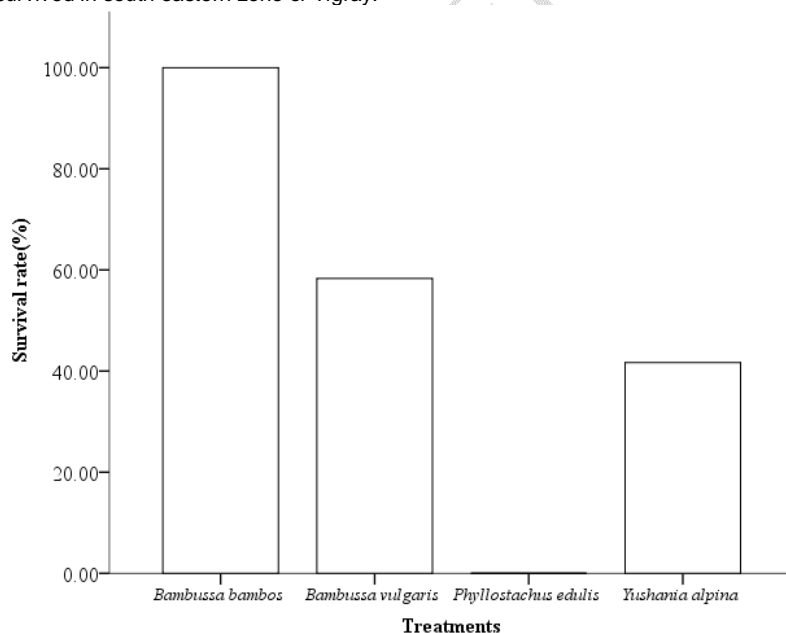


Figure 2: The survival rate (%) of introduced bamboo species

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3.2. Growth performance of the different bamboo species

3.2.1. Number of new emerging shoots (culm)

The production of new culms per clump of bamboo species depends mostly on the clump age, nutrient storage and the rainfall availability [21, 22]. In this study, there was a significant variation of culm number between the treatments (*Bambusa bambos*, *Yushania alpina* and *Bambusa vulgaris*). The number of culms for *Bambusa bambos* was significantly higher than *Yushania alpina* and *Bambusa vulgaris* (at $P=0.001$). However, the number of culms between *Yushania alpina* and *Bambusa vulgaris* were observed non-significant variation at $P>0.05$ (Table 1). Similar result was reported that the highest mean number of culms per clump of *Bambusa balcoo* was 19.44 [22, 9]. However, this result is in the contrary to [18] which indicates, the number of culm per clump of *Bambusa bambos* is lower as compared to *O. abyssinica*. Even though the number new shoots of *Bambusa bambos* (109) exhibited superiority over *Bambusa vulgaris* (75) by producing maximum number of culms in the trial, very close number of culms per clump (66) of *Bambusa vulgaris* was reported in south-western Ethiopia [23]. The variation of new emerging shoot could be due to the variation of agro ecological zones and the species characteristics.

3.2.2. Culm Diameter (CD, DSH and DBH)

The culm diameter of bamboo species varies depending on the type of species, age and environmental condition [24]. For most bamboo species, their culms can reach maximum diameters at around two to three years of age [25]. In this study the mean value of the parameters (CD, DSH and DBH) were observed highly significant different at $P=0.001$ (Table 1). The mean collar diameter, diameter at stump height and diameter at breast height of *Bambusa bambos* was significantly higher than *Yushania alpina* and *Bambusa vulgaris* (at $P=0.001$). However, for a similar parameters: *Yushania alpina* was shown non-significant variation with *Bambusa vulgaris* (at $P>0.05$). The variation of diameter size between the bamboo species might be due to the growth characteristics of the different bamboo species and environmental factor (low rainfall availability). This result is in lines with [24, 25], soil quality, water availability and climate are the factors which influence the culm diameter of bamboo species; in which these factors make a variation even with in the same species in different location. Other findings similar to this study were reported by [26, 27], a significant variation of the culm diameter between the difference bamboo species might be due to the growth performance and adaptability potential of the species.

3.2.3. Culm Height (m)

The mean height between treatments (*Bambusa bambos* (5.1m), *Yushania alpina* (4.5 m) and *Bambusa vulgaris* (4.2 m)) were observed statistically non-significant different at $P=0.262$ (Table 1). The result agreed with [28], which shows that, the Culm height for *Dendrocalamus hamiltonii* (5.34m), *Dendrocalamus membranaceus* (4.95 m) *Oxytenanthera abyssinica* (3.84 m) and *Dendrocalamus asper* (3.81 m) showed statistically non-significant difference in height at the age of four years of establishment. The culm height of *Bambusa bambos* and *Bambusa vulgaris* aligns with previous research conducted in south eastern Tigray, in which *Bambusa bambos* (2.26 m) and *Bambusa vulgaris* (2.35 m) shows non-significant height variation [18]. Other similar results were reported by [29], the culm height of matured *Dendrocalamus hamiltonii* has 20 meter and *Dendrocalamus asper* has 20-30 meter which is almost similar among the species. This could be due to the similar growth characteristics of the species for a certain age. However, the full length of emerging shoot is varied among the species; this might be due to the species adaptability and performance conditions variation [26].

Table 1. ANOVA table for means \pm SE comparison between treatments at 0.05 significant levels (Mean \pm SE).

Treatments	Parameters
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	Culm no.	CD(cm)	DSH(cm)	DBH(cm)	Height(m)
<i>Bambussa bambos</i>	109 ±15.7a	3.85 ±0.19a	3.38 ±0.15a	2.97 ±0.19a	5.1 ± 0.4a
<i>Yushania alpina</i>	53 ±12.6b	2.13 ±0.15b	1.97 ±0.16b	1.84 ±0.19b	4.5 ±0.2a
<i>Bambussa vulgaris</i>	75 ±31.7b	1.89 ±0.13b	1.55 ±0.09b	1.5 ±0.02b	4.2 ±0.5a
P-value	0.001	0.001	0.001	0.001	0.262

Means of the treatments in a column with similar lowercase letters are not significantly different ($P>0.05$), while the difference letters in column indicates significant difference ($P<0.05$) between the treatments. Culm no. -culm number, CD-collar diameter (cm), DSH-diameter at stump height (cm), DBH-Diameter at breast height (cm).

3.2.4. Number of Nodes and Internodes Length

The culm structure of all bamboo species is cylindrical and is divided into sections by nodes. Inter nodes are hollow in most bamboos, but solid in some species. Bamboo internodes length can indicate the quality of bamboo product which used for different purpose. In this study, the mean value for the parameters (number of nodes, lower internode length (LIL) and Upper internode length (UIL)) between treatments were showed statistically non-significant different at $P>0.05$ (Table 2) and this is in the contrary to [5, 26, 28] result which says, the mean value for the number of node was revealed a significant difference between the different bamboo species in different study sites. This could be due the unique characteristics of the bamboo species across different locations. However, the mean value of total internode length (TIL) and middle internode length (MIL) was observed a significant difference between treatments at $P<0.05$ (Table 2). The highest mean was observed from *Bambussa bambos* and followed by *Yushania alpina*, while the least mean was recorded from *Bambussa vulgaris*. The result disagreed with [18], the average internode length of *Bambussa bambos* was non-significant difference with *Bambussa vulgaris* in south eastern Tigray. The significant variation of internode length between the treatments across different study areas might be due the age of establishment, species type, water availability and site conditions.

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Table 2. ANOVA table for means ±SE comparison of Bamboo species at 0.05 significant levels (Mean±SE).

Treatments	Parameters				
	No. Nodes	TIL(cm)	LIL(cm)	MIL(cm)	UIL(cm)
<i>Bambussa bambos</i>	28±1.1a	27.07±0.8a	30.9±1.3a	30.8±0.8a	19.5±0.3a
<i>Yushania alpina</i>	24±3a	24.26±0.9a	31.6±1.6a	26.7±1.1ab	14.8±1.5a
<i>Bambussa vulgaris</i>	18±2.4a	19.9±1.1b	26.3±3.2a	19.6±2.6b	12.9±2.3a
P-value	0.076	0.002	0.254	0.01	0.063

*Statistically the mean values with the same letter in the column are not significantly different ($P>0.05$), while the difference letters in column indicates significant difference ($p<0.05$) between the treatments. No. Nodes-Number of nodes, TIL- Total internode length (cm), LIL- Lower internode length (cm), MIL- Middle internode length (cm), UIL- Upper internode length (cm).

4. CONCLUSIONS AND RECOMMENDATIONS

This study provides useful evidence on the growth performance and adaptability potential of four exotic bamboo species in central Tigray, Ethiopia. The study revealed that, among the four bamboo species, *Bambussa bambos* showed higher growth performance and adaptability potential followed by *Yushania alpina* and *Bambussa vulgaris*.

As a result, the best-performing introduced bamboo species is *Bambussa bambos* and should be promoted to end users in related agro-ecological areas for various uses. Additionally, it needs training for the local communities, stakeholders and small enterprises on the production and management of the

introduced bamboo species. Further studies should be recommended on the adaptability of these species in other agro-ecologies.

Availability of data and materials;All the data's and materials used in this article are available from the corresponding author.

REFERENCES

1. Liese W. Anatomy and properties of bamboo. In Proceedings of the International Bamboo Workshop, 1985(6), pp. 196-208.
2. Wang X. Comparative analysis and policy recommendations on developing bamboo resource tenure systems in Asia and Africa. *Bamboo for the Environment, Development and Trade*. 2006 Oct 23;148.
3. Oumer OA, Dagne K, Feyissa T, Tesfaye K, Durai J, Hyder MZ. Genetic diversity, population structure, and gene flow analysis of lowland bamboo [*Oxytenanthera abyssinica* (A. Rich.) Munro] in Ethiopia. *Ecology and evolution*. 2020 Oct;10(20):11217-36. <https://doi.org/10.1002/ece3.6762>
4. John CK, Nadgauda RS. Bamboo flowering and famine. *Current science*, (2002): 82 (3): 261-262.
5. Diriba, A., Dekeba, S. & Gizaw, W. Adaptation and Growth Performance of Lowland Bamboo Species in West Hararghe, Mechara on Station. *Octa Journal of Environmental Research*, 2019, (7), 087-092.
6. Lohani TK, Sigu G, Oduor N, Reza S, Durai J. Species-Site Suitability Assessment of Bamboo and Its Detailed Study in Different Agroecological Zones of Kenya. *International Journal of Forestry Research*. 2023;2023(1):8859316.
7. Banik RL. Distribution, diversity and prospects for propagation of industrially suitable bamboo species in India. (2020): 52-69.
8. Kaminski S, Lawrence A, Trujillo D. Structural use of bamboo: Part 1: Introduction to bamboo. *The structural engineer*. 2016 Aug; 94(8):40-43.
9. Yigardu, M., Asabeneh, A., & Zebene, T. Bamboo species introduced in Ethiopia: Biological, Ecological and Management Aspects. 2016 (2-3), 75.
10. Bystriakova N, Kapos V, Lysenko I. Bamboo biodiversity: Africa, Madagascar and the Americas. No.19. UNEP/Earth print; 2004.
11. Kigomo BN. Distribution, cultivation and research status of bamboo in Eastern Africa. *Ecology Series Monograph*, 1988: 1-19.
12. Embaye K. The indigenous bamboo forests of Ethiopia: an overview. *AMBIO: A Journal of the Human Environment*. 2000 Dec;29(8):518-521.
13. Embaye K. Ecological aspects and resource management of bamboo forests in Ethiopia. Uppsala, Sweden: Swedish University of Agricultural Sciences; 2003 Apr 1.
14. Bekele-Tesemma A, Tengnäs B. Useful trees and shrubs of Ethiopia: identification, propagation, and management for 17 agroclimatic zones. Nairobi: RELMA in ICRAF Project, World Agroforestry Centre, Eastern Africa Region; 2007.
15. Office of Agriculture and Rural Development of Laelay Maichew district. Annual Report. (2014).
16. Zeleke A, Ararso LC. Adaptation and Growth Performance of Different Introduced Lowland Bamboo Species in Central Tigray, Ethiopia. *Kastamonu University Journal of Forestry Faculty*.2023; 23(2):165-74.

17. Kibwage JK, Netondo GW, Odondo AJ, Oindo BO, Momanyi GM, Jinhe F. Growth performance of bamboo in tobacco-growing regions in South Nyanza, Kenya. *African Journal of Agricultural Research*.2008, 3(10), 716-724.
18. Eyasu G, Gebrewahid Y, Darcha G, Kassa H. Adaptation and growth performance of different bamboo species in Dryland areas of Northern Ethiopia. *Forest Science and Technology*. 2024 Apr 15:1-6.
19. Wu ZY, Raven PH, Hong DY. *Flora of China*: Missouri Botanical Garden, St. Louis, Missouri and Harvard University Herbaria, Cambridge, Massachusetts.2004.
20. Shi L, Fan S, Jiang Z, Qi L, Liu G. Mixed leaf litter decomposition and N, P release with a focus on *Phyllostachys edulis* (Carrière) J. Houz. forest in subtropical southeastern China. *Acta Societatis Botanicorum Poloniae*. 2015;84(2).
21. Shanmughavel, P. Studies on organic productivity, nutrient distribution, nutrient cycling, pulp and paper characteristics of plantation Bamboo (*Bambusa bambos*Vass) Ph.D.Thesis, Bharathiar University, Coimbatore, 1995.
22. McDowell ET, Gang DR. A dynamic model for phytohormone control of rhizome growth and development. In *Phytochemicals, plant growth, and the environment*.2012 Jul 23 (pp. 143-165).
23. Krishnakumar N, Kanna S, Parthiban KT, Shree M. Growth performance of thorn less bamboos (*Bambusa balcooa* Roxb. and *Bambusa vulgaris* Schrader ex JC Wendland). *International Journal of Current Microbiology and Applied Sciences*. 2017;6(4):32-39.
24. Alemayehu A, Mulatu Y, Eshete N, Terefe M. Growth performance and biomass accumulation of four different introduced bamboo species in South-Western Ethiopia. In "10th World Bamboo Congress". 2015;5(3):5-10.
25. Mohmod AL, Liese W. Culm characteristics of two bamboos in relation to age, height and site. In *Bamboo for Sustainable Development*. 2002 Jan 1 (pp. 223-233). Brill.
26. Singnar P, Nath AJ, Das AK. Culm characteristics and volume-weight relationship of a forest bamboo (*Melocanna baccifera* (Roxb.) Kurz) from northeast India. *Journal of Forestry Research*. 2015 Dec;26:841-849.
27. Diriba A, Dekeba S, Gizaw W. Evaluation of Lowland Bamboo Propagation Techniques in West Hararghe Zone, Oromia Region, Ethiopia. *Journal of Energy and Natural Resources*. 2021 Jul;10(3):65-70.
28. World Scientific News. Highland bamboos species' characteristics. (2017).
29. Abdella M, Cheneke B. Adaptation and Growth Performance of Lowland Bamboo Species at Fedis District East Hararghe Zone, Oromia, Ethiopia. *American Journal of Plant Biology*. 2023 Feb;8(1):6-11.
30. Singh J, Sharma R, Dhakad AK, Chauhan SK. Defining growth, quality and biomass production of different bamboo species in central plains of Punjab. *Journal of Pharmacognosy and Phytochemistry*. 2018;7(5):1328-32.