American Journal of Agricultural Science, Engineering, and Technology (AJASET)

ISSN: 2158-8104 (ONLINE), 2164-0920 (PRINT)

VOLUME 8 ISSUE 3 (2024)

PUBLISHED BY: E-PALLI PUBLISHERS, DELAWARE, USA

American Journal of Agricultural Science, Engineering, and Technology (AJASET)

Volume 8 Issue 3, Year 2024
ISSN: 2158-8104 (Online), 2164-0920 (Print)
DOI: https://doi.org/10.54536/ajaset.v8i3.2439
https://journals.e-palli.com/home/index.php/ajaset

Effect of Provenance Variation on Growth Performance of Indigenous Highland Bamboo Species (*Arundinaria alpina*), in Bore District, Southern Ethiopia

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Article Information

Received: January 03, 2024

Accepted: February 07, 2024

Published: November 14, 2024

Keywords

Arundinaria Alpina, Dimtu Hambela, Growth Performance, Indigenous Highland Bamboo Species, Injibara, Provenance Variation, Shanan

ABSTRACT

Bamboo is widely recognized as a highly renewable, fast-growing, economic raw material. Moreover, bamboo has the capability of mitigating climate change as it restores degraded land , act as carbon sequesters and protects from soil erosion. The study evaluated the effects of provenance variation on growth performance of indigenous highland bamboo species (*Arundinaria alpina*) in Bore District, Southern Ethiopia. Three provenances of indigenous highland bamboo species (*Arundinaria alpina*) such as Dimtu Hambela, Injibara and Shanan were collected from different parts of the country. Those collected provenances were planted in Bore Agricultural Research Center, on station in a Randomized Complete Block Design in three replications. Dimtu Hambela provenance had higher survival rate (85.1%) followed by Shanan (65.6%) and Injibara (64.8%) provenances. The maximum number of new emerged shoots (21.3) and number of nodes (29.9) were recorded in Dimtu Hambela provenance. In terms of root collar diameter and diameter at breast height, Dimtu Hambela provenance had (3.01cm) and (3.56cm) respectively. However, root collar diameter (2.23cm) and (2.12cm) and diameter at breast height (1.72cm) and (2.36cm) were recorded from Injibara and Shanan provenances respectively. Moreover, the highest internode length (32cm) and culm height growth (5.7cm) was recorded from Dimtu Hambela provenance followed by Shanan and Injibara provenances. Therefore, based on their growth performances Dimtu Hambela and Shanan provenances of indigenous highland bamboo species (*Arundinaria alpina*) were recommended and they could be demonstrated and popularized around Bore district and in similar climatic condition. Furthermore, vegetative propagation study of the recommended provenances should be mandatory in order to expand the indigenous highland bamboo resources.

INTRODUCTION

Bamboo is one of the world's most important non-timber forest products (NTFPs) and managed bamboo harvesting and marketing has been advocated for poverty alleviation in many regions (Singh, 2008). Cultivation of bamboo can provide a cost-effective return in the short term and can provide significant proportion of the national income since it is a multipurpose grass useful for day-to-day life of people (Shanmughavel & Peddappaiah, 2000; Ray & Ali, 2017).

It is envisaged that bamboo would be a significant means for a sustainable and widespread development, augmenting economic opportunity, income and employment, especially in relatively under developed areas of the globe. It is also an eco-friendly alternative material easily processed by simple technologies (INBAR, 2015). Bamboo is widely recognized as a highly renewable, fast-growing, and economical raw material. Products from bamboo are grouped into industrial use, food products, construction and structural application, wood substitutes and composites, and cottage and handicraft industry. As well, bamboo has the capability of mitigating climate change as it restores degraded land , act as carbon sequesters and protects from soil erosion(Kelbesa *et al.*, 2000; Njuguna & Kigomo, 2008).

Nowadays, there are two indigenous and 27 introduced bamboo species are found in Ethiopia (Embaye, 2000; Huojin, 2014). Accordingly, Ethiopia has a huge amount of bamboo resource in total area coverage in Africa. It covers 1.44 Million ha (Zhao, 2018), which is about 7% of the world total and 67% of the African bamboo forest area (Embaye, 2000). Among these number of species highland bamboo (*Arundinaria alpina*) and lowland bamboo (*Oxytenantheria abyssinica*) are the two indigenous species found in Ethiopia with 15% and 85% proportions from whole bamboo resource of the country (Desalegn & Tadesse, 2014; Mulatu & Fetene, 2014).

Highland bamboo (*Arundinaria alpina*) is a species that is grown and distributed around South, South-west, Central and North-west highlands areas of the country, which is between altitudinal ranges of 2200 m to 4000 m above sea level (Nduwamungu, 2018). The highland bamboo resource is relatively small in area coverage. However, it is preferred by craftsmen and is better utilized compared to the lowland bamboo. Studies on its wood properties proved that the highland bamboo species fulfills the ISO standards for industrial products (FRIM, 2008). Moreover, studies show that a number of industrial bamboo products including pulp and paper, charcoal, furniture, and edible shoots can be produced from highland bamboo species (Kelemework *et al.*, 2008).

Provenance research aims at defining the genetic and

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environmental components of phenotypic variability between trees from different geographic locations (Callaham, 1962). The broad scope of provenance research involves all studies above the level of the individual and below the level of the species. Therefore, the investigation of provenance is the study of ecological variability within species, the relationship between this variability and the influence of the environment,and the reactions of different populations to transfer to an environment foreign to them (Langlet, 1962). This is because provenance variation is directly associated with a variation in their adaptation potential at a particular area. Moreover, studies have also shown that provenance variation affects the functional characteristics of seedlings and their field performance (Savil *et al*., 1997) .

In Ethiopia, in recent years, interest has also increased in the ecological restoration of especially degraded areas through reforestation and afforestation programs. In order to capitalize on advances made in such programs, suitable provenance selection and successful establishment of highland bamboo species (*Arudinaria alpina*) seedlings at the field level are very significant. Therefore, in order to cover the degraded areas with fast-growing plants like highland bamboo provenances, there is always a need for a well-conducted field trial for matching the highland bamboo provenances to a particular area. Therefore, the study's overall objective was to evaluate the effect of provenance variation on growth performances of indigenous highland bamboo species (*Arundinaria alpina*) in Bore District, Southern Ethiopia.

MATERIALS AND METHODS

Description of study area

Location

The study was conducted in Bore District of Guji Zone, in Southern Ethiopia. The study district is located 385 km to the south of Addis Ababa, the capital city of Ethiopia. The study area is located within the latitude 6°22'30"-6°25'50" N and longitude of 44°32'30"-44°35'50" E (Figure 1).

Climate

The study district is characterized by two agroclimatic zones, namely humid which start in early April to November and sub-humid which starts late December up to beginning of March. The mean annual rainfall of the study area ranged from 1400-1800mm with a bimodal pattern that is extended from April to November. The mean annual minimum and maximum temperature of the study district are 10°C and 20°C respectively.

Soil and Vegetation

The major soil of the study district are Nitosols (red basaltic soils) and Orphic Acrosols. The two soil types are found on the highland areas, and they are red brown and black brown in colors and on sloping topography and their utilization are good under natural vegetation. In terms of vegetation types, the following tree species such as *Erythrina abyssinica, Eucalyptus camaldulensis, Hagenia abbysinica, Juniperus procera, Pinus patula* and *Schefillera abbysinica* are commonly growing in the study district. Moreover, from non-timber forest products highland bamboo (*Arudinaria alpina*) is also growing in the study district.

Agricultural Activities

The farmers of Bore district produce cereal crops such as wheat, barley and maize, pulse crops such as faba bean and field pea. Moreover, farmers of the study district produce horticultural crops such as potato, head cabbage and other vegetables.

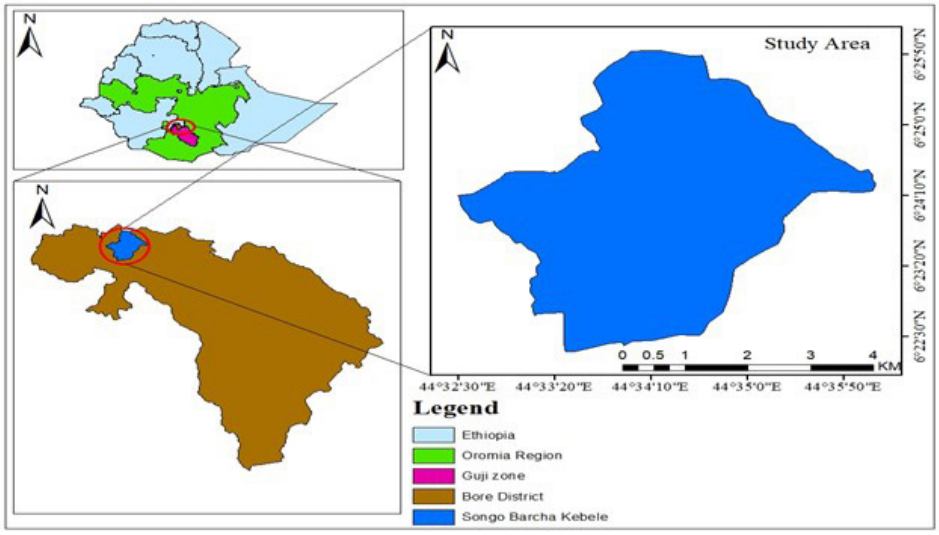

Figure 1: A map showing the study area

Collection of planting materials

The three planting materials of Highland bamboo species(*Arundinaria alpina*) provenances were collected from different parts of the country (Table 1). Accordingly, from Oromia and Amhara National Regional state the following highland bamboo provenances such as Dimtu Hambela, Injibara and Shanan were collected from their sources and used on this study.

Table 1: Planting materials collection area of Highland bamboo species (*Arundinaria alpina*) provenances

Highland bamboo provenances	Collection area of highland bamboo provenances			
	District	Zone	Regional State	Country
Dimtu Hambela	Dimtu Hambela	Guji	Oromia	Ethiopia
Injibara	Injibara	Awi	Amhara	Ethiopia
Shanan	Shanan	West Shewa	Oromia	Ethiopia

Experimental design

The growth performance of the highland bamboo provenances were conducted for consecutive four years, from 2020-2023 study time. Those collected provenances were planted in Bore Agricultural Research Center, at Songo Berecha research station in a Randomized Complete Block Design (RCBD) in three replications. The seedlings were planted in a plot size of 9mx9m. On each plot, at spacing of three meters nine seedlings of highland bamboo provenances were planted. The space between plants and blocks used on this study were 2m and 3m respectively.

Field Management

After seedlings of the highland bamboo provenances were planted in the experimental fields, different field managements such as watering supply, mulching, hoeing, weeding and necessary plant protection were performed until the end of study time.

Data Collection

During the study time, the following parameters including survival rate (%), root collar diameter, number of nodes, number of new emerged shoots, internode length, culm height and culm diameters were collected at the interval of three months. Culm height was measured using Meter tape in centimeter (cm) from the soil surface to the tip of the bamboo culm main axis. Where as, root collar diameter was measured using caliper near the soil surface.

Data Analysis

Analysis of variance was computed using Genstat software (18th edition) package to test the significant difference among the highland bamboo provenances. Least significant different (LSD) test was employed to separate statistically different means using the soft ware package at 0.05 level of probability.

RESULTS AND DISCUSSION

Survival rate of the provenances

Figure 2 shows the survival rate of the highland bamboo provenances their growth performances were studied. Based on the findings of the current study, the highland bamboo species (*Arundinaria alpina*) provenances showed variation in their survival rate. The highest survival rate of (85.1%) was recorded from Dimtu Hambela provenance. However, the survival rate of Shanan and Injibara provenances were (65.6%) and (64.8%) respectively (Figure2). The significant variations of the survival rate recorded among the three highland bamboo provenances could be due to environmental factors. In support of this study, in their former research findings, Evans *et al.*, 1992 point out that the survival rate of tree species depends on the genetic variability and their adaptability to the environment. Environmental factors such as pest attack, planting technique, weather condition, weed competition and poor soil conditions are the factors possibly lead to variations in survival rate and growth performance.

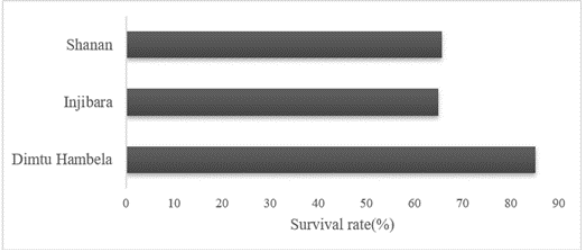

Figure 2: Survival rate of the *Arundinaria alpina* provenances

Number of shoots

Bamboo shoots/bamboo sprouts are one of the young expanding buds from the rhizome of bamboo cut as soon as it appears above ground. The findings of this study showed that, in terms of number of new emerged shoots a significant differences were recorded among the highland bamboo (*Arundinaria alpina*) provenances (Table 2). This could be due to environmental factors affecting growth performances of the studied highland bamboo provenances such as climate, soil, topography and biota. Because, each bamboo provenances adapted to these factors in an integrated way, that is by evolving sup-populations adapted to the constraints of their particular environments.

According to the combined analysis results of the four years data, Dimtu Hambela's provenance (21.3) showed a significant difference in a number of new emerging shoots throughout the study years.However, the number of newly emerged shoots of the Injibara and Shanan highland bamboo provenances were (12.6) and (9.7) respectively. From the current study as well observed that the examined highland bamboo provenances sprouted new shoots during the rainy season of the study area. In agreement with this study, in their former research findings (Batabyal & Tah, 2013; Yared *et al.*, 2017) indicated that a high number of highland bamboo shoots were emerged during the wet season.

Root Collar Diameter

Root collar diameter has a significant impact on seedling quality. Various studies have shown that an increase

in root collar diameter is positively associated with an increase in seedling height and a seedling with a large root collar diameter can produce more wood in a shorter time than its average to smaller counter parts. During the study period a significant variations($p<0.05$) in root collar diameter growth was observed among the *Arundinaria alpina* provenances (Table 2). The maximum root collar diameter was recorded in Dimtu Hambela (3.01cm) provenance followed by Injibara (2.23cm) and Shanan (2.12cm) highland bamboo provenances and it was significantly ($p<0.05$) higher than the other. In contrary to this study, Tinsae Bahru *et al.* (2018), in their study results of provenance variation on early survival rate and growth performance of *Oxytenanthera abyssinica* reported that a significant difference was not observed between the lowland bamboo provenances.

Even though, there is no statistically significant difference in growth of root collar diameters was recorded between the Injibara and Shanan highland bamboo provenances (Table 2). Therefore, the higher root collar diameter recorded in Dimtu Hambela provenance indicated the quality and productivity of the provenance. Because, in different study results reported that root collar diameter is vital to predict the quality of tree species. In support of the current study, (Shumi *et al.*, 2012; Bahru *et al.*, 2014) in their study results conducted on effects of provenance on seed germination, early survival and growth performance of *Juniperus procera* and *Tamarindus indica* tree species respectively, reported the significant of higher root collar diameter on growth performances of the seedlings.

Table 2: Highland bamboo provenances growth performance parameters, in Bore District,Southern Ethiopia

Highland bamboo provenances	NOS	RCD(cm)	DBH(cm)	NOD	INL(cm)	CH(m)
Dimtu Hambela	21.3[a]	3.01[a]	3.56[a]	29.9[a]	32[a]	5.7[a]
Injibara	12.6[b]	2.23[b]	1.72[c]	16.4[b]	23[b]	4.6[c]
Shanan	9.7[c]	2.12[b]	2.36[b]	19.2[b]	30[a]	5.4[b]
Mean	14.5	2.45	2.51	21.83	28.11	5.26
CV(%)	12.7	3.7	6.2	8.9	5.9	2.5
LSD(5%)	4.2	0.21	0.35	4.4	3.77	0.29

**Means values in the same column with the same letter are not significantly different, NOS-Number of shoots, RCD- Root collar diameter, DBH- Diameter at breast height, NOD-Number of nodes,INL-Internode length,CH-Culm height*

Diameter at breast height

Diameter at breast height (DBH) of trees is an important indicator of forest ecological investigation and forest resource research (Yang *et al.*, 2020). Specifically, the tree has to increase its DBH continuously to resist harsh environments and the diameter at breast height has good correlation with branch diameter, tree taper, tree height and crown size (Huang *et al.*, 2012).The results of the current study revealed that, the highest mean diameter at breast height (3.56cm) was recorded from Dimtu Hambela provenance and it was significantly ($p<0.05$) higher than the other. However, diameter at breast height of the Shanan and Injibara highland bamboo provenances were (2.36cm) and (1.72cm) respectevely (Table 2). The differences in DBH development could be attributed to variations in adaptability among the highland bamboo provenances. Moreover, the influence of climatic condition variability such as rainfall and temperature and the genetic variation of the provenances could have contributed to differences in growth performances of the studied highland bamboo species (*Arundinaria alpina*) provenances.

Number of nodes

The node is the basic characteristic of bamboo plants and plays a key role in the overall performance of the hollow structure of bamboo culms (Liu *et al.*, 2015; Zou *et al.*, 2016). Nodes are also one of the important characteristics of bamboo culms and prevent the deformation and cracking of internodes (Wang *et al.*, 2013; Shima *et al.*, 2016). Based on the findings of the current study, in terms of number of nodes highly significant variations ($p<0.05$) were recorded among the highland bamboo provenances (Table 2). Accordingly, the highest mean number of nodes (29.9) was registered in Dimtu Hambela provenance. Where as, from the Injibara and Shanan highland bamboo provenances the recorded mean number of nodes were (16.4) and (19.2) respectively. In support of this study, the internode length and number of nodes per culm of bamboo were significantly different in different bamboo species, but they did not differ significantly in different age of culm (Nirala *et al.*, 2015). Moreover, Krishnaswamy (1956) reported that different bamboo species vary considerably in their number of nodes depending on the species, locality and vigour of the culm.

Internode length

Internode length could indicate higher strength of mechanical properties of engineering composite products due to its continuous fibre length.The maximum length of fiber is determined by the length of the internodes, but the volume of extracting fibers is determined by the internodal diameter and culm wall thickness (Shahril & Mansur, 2009). From the results of this study observed that, significantly higher internode length were recorded in

Dimtu Hambela (32cm) and Shanan (30cm) provenances than that of Injibara (23cm) provenance (Table 2). The differences observed in internode length of the studied highland bamboo provenances could be due to the length of bamboo internodes varies greatly from species to species, provenance to provenance and the climate and soil it is grown in. In agreement with the current study, in their former research findings Anonymous, (2009) and Nath *et al.* (2009) also reported different internode length in different bamboo species.

Furthermore, the findings of the current study showed that internode length of the investigated *Arundinaria alpina* provenances were showed varying lengths and increased from the bottom to the mid-section and then decreased toward the top (Figure 3). In support of this study similar results were obtained by (Nordahlia *et al.*, 2001). In their study results reported that, the highest internode length value was found in the basal and middle portion of the culm. While, the shortest internode length was found at the top of the bamboo culm. Moreover, Dransfield and Widjaya (1995) showed that the mid-section of the internode was longer in size than the bottom and top section of bamboo culm. However, in-contrary to this study Atmawi & Apri, (2018) and Awotwe Mensah *et al.* (2021) indicated that generally internode length gradually increases from bottom portion through to the top portion in both juvenile and mature bamboo culms.

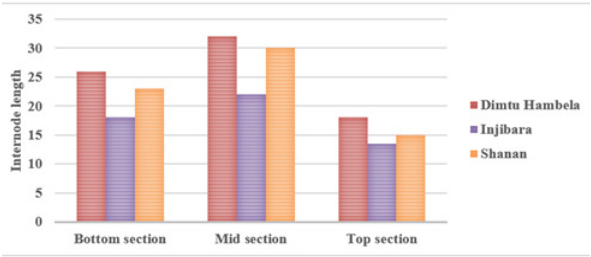

Figure 3: Internode length of the highland bamboo provenances in different sections of culm

Culm height

The bamboo culm is the above ground part of the bamboo that contains most of the woody material. The culm is complimented by a branching system, sheath, foliage, leaves, flowers, fruits and seedlings. Based on the findings of this study, in terms of culm height growth a significant differences were recorded among the highland bamboo provenances (Table 2). The tallest culm height (5.7m) was registered in Dimtu Hambela provenance and it was significantly ($p<0.05$) higher than the other provenances. However, the recorded culm height length of the Shanan and Injibara highland bamboo species (*Arundinaria alpina*) provenances were (5.4m) and (4.6m) respectively. In line with the current study, Tinsae Bahru *et al.* (2018) reported a significant difference in culms height between provenances of lowland bamboo species. The variations observed in culm height growth of the examined highland bamboo provenances may be due to environmental factors such as rainfall, temperature and soil types. In favour of the current study, Pathak *et al.* (2015) reported that bamboo culm height is significantly influenced by the prevailing climatic conditions.

Correlation of the highland bamboo provenances growth variables

The results of Pearson correlation analysis showed that, culm height of the highland bamboo provenances had a strong positive correlation with root collar diameter($r = 0.831$; $p < 0.05$) diameter at breast height ($r = 0.861$; $p < 0.05$) and internode length ($r = 0.863$; $p < 0.05$). On the contrary, except for root collar diameter, diameter at breast height, internode length and culm height growth which had a significant correlation at $p < 0.05$, number of nodes and number of new emerged shoots had no significant correlation ($p < 0.05$) with other growth variables. These results are partly consistent with study results of (Tinsae Bahru *et al.*, 2018). In their study results indicated that, height and root collar diameter growth of indigenous lowland bamboo provenances had significant correlation ($p < 0.05$). Moreover, the findings of this study is supported with Tian *et al.* (2017), who reported that seedling height has a highly significant positive correlation ($p < 0.01$) with other growth variables. In their study findings, Huang *et al.* (2012) also showed that diameter at breast height (DBH) has good correlation with tree height.

Table 3: Pearson correlation analysis of growth performance parameters of highland bamboo provenances

Variables	**Number of shoot**	**Number of nodes**	**Root collar diameter (cm)**	**Diameter at breast height (cm)**	**Internode length(cm)**	**Culm height(m)**
Number of shoot	1					
Number of nodes	0.214NS	1				
Root collar diameter(cm)	0.132NS	0.122NS	1			
Diameter at breast height(cm)	0.121NS	0.145NS	0.689*	1		
Internode length(cm)	0.101NS	0.696*	0.869*	0.863*	1	
Culm height(m)	0.341NS	0.212NS	0.831*	0.861*	0.863*	1
**Correlation is significant at the 0.05 level, NS: Non significant*						

CONCLUSION

Provenance information is important in assuring sources of seed to give well-adapted, productive trees and in directing breeding of interracial and inter-specific hybrids toward adaptation to particular localities. The effects of provenance variation on growth performance of the Highland bamboo species (*Arundinaria alpina*) showed that, among the provenances significant differences were observed. From the three studied highland bamboo provenances, (85.1.%) survival rate was recorded in Dimtu Hambela provenance, followed by Shanan (65.6%) and Injibara (64.8%) provenances. Moreover, in terms of other growth parameters, such as newly emerged shoots and nodes, (21.3) and (29.9) were recorded in Dimtu Hambela provenance, respectively. However, the minimum number of newly emerged shoots (9.7) and number of nodes (16.4) were obtained from Shanan's and Injibara's provenances, respectively. Similarly, the maximum (3.01cm) root collar diameter and (3.56cm) diameter at breast height was recorded from Dimtu Hambela provenance. Where as, in root collar diameter a significant variations were not observed among the Injibara and Shanan provenances and the minimum (1.72cm) diameter at breast height was recorded in Injibara provenance. This study also showed that, in terms of internode length and culm height growth parameters the highest (32cm) internode length and (5.7cm) culm height was recorded from Dimtu Hambela provenance, followed by Shanan provenance (30cm-internode length and 5.4cm-culm height growth). Based on the study results of the effects of provenance variation on growth performance of indigenous highland bamboo species (*Arundinaria alpina*), Dimtu Hambela and Shanan provenances had better growth performance respectively. Therefore, Dimtu Hambela and Shanan could be demonstrated and popularized around Bore district and in areas that have similar climatic condition. Further more, vegetative propagation study of the two provenances should be mandatory in order to expand the highland bamboo resources of the study area.

Acknowledgments

The authors express their gratitude to the staff of Agroforestry Research Team of Natural Resource Research Process for their follow-up and data collection. Moreover, the authors thanks Bore Agricultural Research Center for provision of the necessary facilities for research and Oromia Agricultural Research Institute for its financial support.

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