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Research Article

Provenance Variation on Early Survival Rate and Growth Performance of *Oxytenanthera abyssinica* (A. Rich.) Munro Seedlings at Green House: An Indigenous Lowland Bamboo Species in Ethiopia

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Background. Lowland Bamboo (*O. abyssinica*) is an indigenous multipurpose species in Ethiopia and endemic to Africa. *Aims*. The present study was aimed at investigating provenance variation on early survival rate and growth performance of *O. abyssinica* seedlings so as to obtain suitable provenance for production of high quality seedlings. *Methods*. Seeds were collected from Pawe and Sherkole districts. Following raise of seedlings data on survival count, culm height, root collar diameter (RCD), number of leaves, and biomass were recorded. *Results*. Pawe provenance had slightly higher survival rate (91%). Except seedlings RCD, rhizomes length, and roots fresh and dry weights, higher mean values of other morphological parameters were recorded in Sherkole provenance. Biomass of leaves and culms was higher in Shekole provenance, while root biomass was exceeded by the Pawe provenance. However, significant variations ($P<0.05$) between provenances were observed in RCD, rhizomes length, weight of fresh culms, and fresh and dry root system. Seedlings growth parameters (height and RCD) were positively and significantly correlated with Biomass variables and hence could be considered as better evaluation criteria for seedling quality at green house. *Conclusion*. Sherkole provenance should be considered for raising *O. abyssinica* seedlings at green house.

1. Introduction

Bamboo belongs to the subfamily *Bambusoideae* and family *Gramineae* or *Poaceae* [1, 2]. There are at least 90 genera [3] and more than 1,575 Bamboo species [2] are distributed throughout the world. Nowadays, there are two indigenous [4] and 27 introduced [5] Bamboo species are found in Ethiopia. As a result, Ethiopia has a huge amount of Bamboo resource in total area coverage in Africa. It covers 1.44 Million ha [6], i.e., about 7% of the world total and 67% of the African Bamboo forest area [4]. Among these, *O. abyssinica* (lowland Bamboo) is an indigenous Bamboo species in Ethiopia and endemic to Africa [4]. In Ethiopia, the species is found in lowland regions of western and northwestern parts of Ethiopia [7] in Tigray, Gonder, Gojam, and Welega Regions [1]. But, recent study conducted by Zhao et al. [6] confirmed that the species is distributed mainly in Benishangul-Gumuz, western part of Amhara and Oromia Regions. In addition, it is widespread in African continent mainly in Ethiopia, Eritrea, Sudan, South Sudan, Uganda, Tanzania, Central African Republic, Republic of Congo, Democratic Republic of Congo, Senegal, Guinea, Sierra Leone, Cote d'Ivoire, Ghana, Togo, Benin, Nigeria, Cameroon, Angola, Zambia, Malawi, Zimbabwe and Mozambique [8], and Asian continent such as India [3, 9], and Vietnam [9]. It is a solid woody clump forming Bamboo growing up to a height of 3-13 m and a diameter of 5-10 cm [1]. It grows in Savanna woodland, along the river valleys and spreads around on the hills, often forming extensive stands [1, 6] at the altitudes ranging from 540 [6] to 1,800 m above sea level (a.s.l.) [1]. The

Table 1: Geographic locations and climatic conditions of *O. abyssinica* seed provenances at Benishangul-Gumuz Regional State, western Ethiopia.

Provenance	District	Geographical location (Lat. & Long.)	Altitude (m a.s.l.)	Rainfall (mm)	Temperature (°C)
Pawe	Pawe	11°20′N; 36°20′E	990	1,587	16.3-32.6
Sherkole	Sherkole	10°40′N; 34°36′ E	875	900-1,200	10.8-42

species annual rainfall ranges from about 700 to 1,000 mm, which is concentrated over a period of three to four months with the mean annual temperature of above 30°C [10]. The species can grow at a minimum temperature of -1°C and prefers moist conditions along waterways [3]. Based on our observation *O. abyssinica* can grow in full sunlight and it is also drought resistant and may be deciduous in hot and dry conditions. The species is easily adaptable to poor soils and could be used to establish buffer zone for desert areas [10]. Consequently, it is one of the most promising Bamboo species in rehabilitation of degraded areas and hence suitable to replace the declining forest resources in Ethiopia.

Although Bamboo has higher biomass production, shorter rotation and fastest growing behavior, agricultural expansion and/or shifting cultivation, and construction and high fuel wood demand, human settlement, and uncontrolled or accidental forest fire are the major bottlenecks for Bamboo resource in Ethiopia. Other factors include limited availability and poor storage of seeds [11, 12] and seedlings, mass flowering and death of Bamboo, and longer flowering intervals and unpredictable flowering time [13]. In the same way, the traditional management system in private Bamboo plantation and even mismanagement of community and/or state owned forests further aggravate the problem of resource depletion. More emphasis is also given to economic returns instead of prior management and conservation of Bamboo. Collectively, more attention is not given by farmers as well as foresters in promoting various Silvicultural practices of either indigenous or introduced Bamboo species [14, 15]. Some of these are hampered regeneration, mismanagement of stand density and age structure, limited soil loosening and fertilizer application, and inappropriate harvesting techniques. For instance, out of nearly 6.5% of the total Bamboo forest in Ethiopia, about 2.2% Bamboo plantation in the highlands [15] might be an indication of such limitation on Bamboo sustainable management and utilization. Therefore, application of silvicultural practices in Bamboo forest and its sustainable use needs very urgent call. During recent years, interest has also been increased to ecological restoration of especially degraded areas through reforestation and afforestation programmes. In order to capitalize on advances made in such programmes, suitable provenance (original geographic source of the seed) selection and successful establishment of *O. abyssinica* seedlings at field is very important. Furthermore, evaluating seedlings outplanting performance at field condition must be an integral part of selecting the provenance with higher adaptation potential. With this end, raising high quality and large number of *O. abyssinica* seedlings for small-scale and large-scale plantation development in Ethiopia from recommended provenance at green house is reasonable. This is because provenance variation is directly associated with a variation in their adaptation potential at a particular area. Recent studies have also shown that provenance variation affects the functional characteristics of seedlings and their field performance. This demonstrates high quality seedlings show substantial survival and growth performance, thus expressing their full establishment and adaptation potential at field condition. Such difference in adaptation potential, in turn, can be demonstrated in various morphological as well as physiological characteristics [16]. Eventually, the research described that this is directly related to a limited probability of inbreeding between provenances and thereby causes always genetic variations. Suitable provenance saves site maintenance costs and reduces the subsequent rotation period. This further enhances the financial returns on overall future reforestation and afforestation programmes at large-scale plantation development. It also diversifies source of income, creates job opportunity, and improves people's livelihoods through small-scale plantation. Collectively, this study on early survival rate and growth performance of the different provenances of Bamboo at green house stage will help to evaluate the suitability of Bamboo provenances for promotion purposes. This further contributes to selection of better provenance for selected areas so as to achieve adaptable seedlings at field condition. Therefore, the present study was aimed at examining the hypothesis: provenance variation has a significant effect on early survival rate and growth performance of *O. abyssinica* seedlings at green house.

2. Materials and Methods

2.1. Description of the Study Site. The experiment was conducted at Central Ethiopia Environment and Forest Research Center (CEE-FRC). The green house is located in the Highland Agro-ecology at the altitude of 2,368 m a.s.l. between 37°04′E Latitude and 09°96′N Longitude. Addis Ababa has a mean annual rainfall of 1,000 mm and a mean monthly temperature of 20°C.

Seeds of *O. abyssinica* were collected from two provenances of Benishangul-Gumuz Regional State, western Ethiopia. These provenances were Pawe and Sherkole districts. The elevation of Pawe is 990 m a.s.l. between 11°20′N latitude and 36°20′E longitude (Table 1). It has a mean annual temperature of 24.52°C and an average annual rainfall of 1,773 mm [17]. In comparison, Sherkole is located between a latitude of 10°40′N and longitude of 34°36′E at 875 m altitudinal level. The mean annual temperature of Sherkole is 10.8 to 42°C, while the total annual rainfall ranges from 900 to1,200 mm [18].

2.2. Seed Collection, Handling, and Processing. Seeds of *O. abyssinica* were collected in December from Pawe and Sherkole provenances. So as to ensure maximum genetic diversity and minimize inbreeding, seeds were collected from selected clumps of Bamboo stands at a distance of at least 100 m apart between them [19]. The collected fresh seeds were put in to perforated plastic bags and safely transported to CEE-FRC, EEFRI. Seeds which had been attacked by insects, physically damaged or decayed were excluded, extracted and cleaned in CEE-FRC seed processing room following the procedures by FAO [20]. Finally, the seeds were placed in perforated plastic bags and stored in cold room at +5°C until the experiment was started as also partially applied by Baskin and Baskin [21]. This enables to maintain the viability of seeds and prevent from insect attack by reducing seed moisture [20, 22]. Storing seeds at lower temperature further slow down the rate of physiological changes of many seeds [21]. Finally, the research also described that seeds were allowed to germinate at laboratory shortly after the collection of seeds, i.e., within a week.

2.3. Seedling Raising at Laboratory. Untreated *O. abyssinica* seeds, which have best germination percentage, were sowed at laboratory [11] on Petri-dishes. The filter paper was kept moist with distilled water as much as possible throughout the entire experimental period. In order to moisten the filter paper, water was added until the paper was saturated. Water was added to Petri-dishes if the water vapour was disappeared from the Petri-dishes. In turn, the Petri-dishes were holding on its side to allow excess water drained from the filter paper [21]. Once seeds were germinated, seeds were transplanted to laboratory plastic Trays (hereafter referred to as Trays), where sand served as germination medium. A seed was considered as germinated when the radicle was penetrated out from the seed coat and clearly appeared visually [11, 12].

2.4. Seedling Transplanting on Polyethylene Pots at Green House. Side by side, 100 polyethylene pots (20 cm height and 20 cm diameter size) per provenance were prepared containing a mixture of 2 part forest soil and 1 part sand (2:1 ratio) to raise the seedlings. Accordingly, using a Completely Randomized Design (CRD) for each provenance, 100 polyethylene pots in 5 replications of 20 polyethylene pots each were established at green house. Following this, 100 *O. abyssinica* seedlings having 2-4 leaves were transplanted to polyethylene pots at green house from each provenance (i.e., Pawe and Sherkole districts). Since the provenances natural range is characterized by moist *Kolla* climatic condition (dry and hot areas), the experiment was conducted at CEE-FRC green house instead of nursery so as to maintain relatively higher temperature. Seedlings survival ability in the green house was supervised until two weeks and the dead seedlings were replaced by other normal seedlings. Watering was done daily early in the morning and late in the evening when it is necessary. Other Silvicultural applications including weeding, hoeing, and inspection of pest and disease were further carried out regularly and when required.

2.5. Determining Early Survival and Mortality Rate of Seedlings. Survival count was conducted between two provenances at the age of two years after the completion of transplanting of seedlings in the polyethylene pots. The percentage survival of each provenance was calculated as the number of Bamboo seedlings survived at the age of two years divided by the total number of seedlings planted multiplied by 100. On the other hand, the mortality rate of each provenance was calculated as the number of dead Bamboo seedlings at the age of two years divided by the total number of seedlings planted multiplied by 100.

2.6. Evaluating Early Growth Performance of Seedlings. Green house data on growth performance of seedlings per provenance was recorded at the age of two years. These parameters included culm height, root collar diameter (RCD), and number of leaves for each seedling. Accordingly, culm height was measured using ruler in centimeter (cm) from the soil surface to the tip of the Bamboo culm main axis, where the newly shoot was emerged. In case of seedling with more than one culm per clump, all culm heights per clump in each pot were recorded and the average culm height was recorded. Root collar diameter was measured using caliper in millimeter (mm) near the soil surface. Similar to culm height, for seedling with more than one culm per clump, all culms RCD per clump in each pot was measured separately and the average culm RCD was recorded. In line with this, the number of leaves in each Bamboo seedling was counted. Furthermore, detail practical observation, taking photos and interpretation, and thereby noting the various morphological and anatomical structures of the seedlings were conducted regularly.

2.7. Seedlings Biomass Estimation at Laboratory. Once the required data on early survival count and growth performance of seedlings were collected at the age of two years, preconditions for seedlings Biomass estimation (fresh and dry weight) were carried out. Hence, using systematic random sampling method, 30 seedlings per provenance were chosen and then each seedling was uprooted separately. During uprooting process, great care was taken to remove the soil from rhizome as well as primary and secondary roots developed from rhizomes. This is because the fine roots were cut and left into the soil so that it affected the length of rhizome and the fresh and dry weights. In turn, careful practical observation, recording information, and taking photos about the overall rhizome system were conducted thoroughly and included under the results and discussion part. Following this, seedling culm was cut at the soil surface using a sharp plant pruning scissor and separated from the rhizome. Data on the length of rhizome, number of clustered rhizomes developed from the main mother culm base, and biomass estimation was recorded. Accordingly, each seedling length of rhizome was measured from the base of mother culm to the tip of the longest rhizome and/or primary and secondary roots using ruler in cm. The number of clustered rhizomes was counted for each seedling. Finally, each seedling leaf, culm, and rhizome was put separately in to

Table 2: Mean values of seedlings early survival rate between two *O. abyssinica* provenances (n=100, mean ± standard deviation (SD)).

t-test	Provenance		t-test for equality of means
	Pawe	Sherkole	
Mean ± SD	0.91 ± 0.29	0.90 ± 0.30	
t-value			0.240
Sig. difference (P<0.05)			0.811
df (Degree of Freedom)			198

the coded Manila Envelope (*Kaki Wereket* (Amharic)). Fresh weight of each seedling leaf, culm, and rhizome was measured using sensitive analytical balance in gram (g). Fresh weight was measured soon not to lose moisture and affect the weight. Following this, each seedling leaves, culms and rhizome with their respective envelopes placed into the dry-oven at a temperature of 73 ± 2°C for 24 hours. Finally, envelops were removed out from the dry-oven and each seedling leaf, culm, and rhizome dry weight was measured as soon as possible not to absorb moisture and affect the weight. The process was continued until insignificant weight difference was observed between dry weights by measuring randomly drawn samples from small, medium, and large weights.

2.8. Statistical Data Analysis. Data were presented using percentages, figures and tables. In addition, statistical tests on seedlings early survival rate and growth performance parameters were subjected to independent-samples t-test using SPSS statistical software package version 20.0 (SPSS inc., IBM, USA) and the results were reported as Mean ± Standard Deviation (SD). The statistical significance difference between treatments at p<0.05 confidence interval was determined. Eventually, the survival and growth performance between provenances were evaluated using suitability index [23]. Thereafter, a two-tailed Pearson correlation analysis (SPSS Inc., IBM, USA) was performed to determine the relationships between Sherkole provenance seedlings growth and biomass variables. At the same time, linear regression equations and coefficient of determination (R^2) were developed for selected variables.

3. Results

The result of the experiment on *O. abyssinica* seedlings showed that seedlings successfully survived and had higher growth performance within two years at green house. Most of the seedlings developed 2-9 culms per clump. A culm is an erect Bamboo stem with branches, twigs, and foliage, while clump is an aggregate of a few to many culms that is developed from the rhizome. Its culm height attained up to 102 cm, while the RCD thickened around 0.5 mm. The present study on both provenances also clearly confirmed that its rhizome is characterized by the formation of clumps and has a short rhizome neck emerged from the mother culm base as shown in Figure 1. More fibrous root systems (rhizome roots developed from the node of the rhizome) were further associated with the rhizome system. Rhizome is the underground root-like stem of Bamboo. Therefore, *O.*

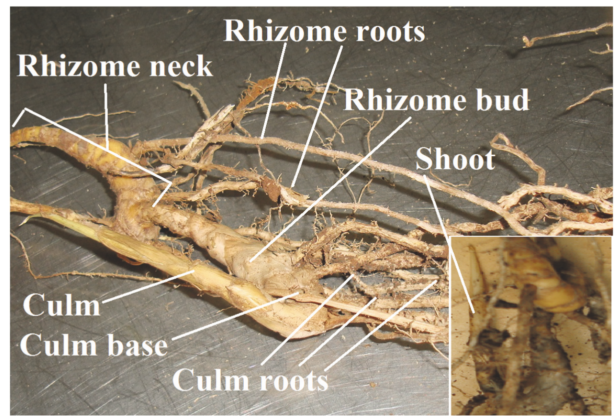

Figure 1: Short-necked pachymorph rhizome type of *O. abyssinica* seedlings at CEE-FRC (**source:** *photo taken by Tinsae Bahru*).

abyssinica seedlings had sympodial or pachymorph rhizome type due to the clumping nature of culms. Based on the present study, the survival, growth performance, and biomass of *O. abyssinica* was presented briefly as follows.

3.1. Effects of Provenance on Seedlings Survival and Mortality Rate. Both provenances successfully survived at green house. The survival rate of seedlings recorded at the age of two years varied from 90 to 91% between provenances (Table 2). Yet, Pawe provenance achieved slightly higher survival rate, which accounted for 91%. In contrast to outperformed seedlings, only a few *O. abyssinica* seedlings were wilted and died over the entire experimental period, i.e., up to 10% of mortality rate. Despite this result the statistical independent-samples t-test for seedlings survival rate reported no considerable variation ($t_{(198)}$=0.24, P=0.81) recorded between provenances.

3.2. Effects of Provenance on Seedlings Early Growth Performance Rate Determination. Data summary and analysis on early growth performance of *O. abyssinica* seedlings were presented in Table 3.

3.2.1. Culm Height . Each *O. abyssinica* seedling at green house demonstrated that the culm had internodes, nodes, culm sheath, and sheath scar. Each culm was separated into a serious of sections called internodes by culm nodes. Culm sheaths were developed on each culm node during the growth of seedlings and tightly overlapped and surrounded the culm internodes. Some seedlings in both provenances

Table 3: Mean values of seedlings early growth performance parameters between two *O. abyssinica* provenances (n=30 or 100, mean ± standard deviation (SD)).

Provenance	Culm height (cm), n=100	No of culms per Bamboo clump, n=100	RCD (mm), n=100	No of leaves, n=100	Length of Rhizomes, n=30	No of clustered Rhizomes (cm), n=30
Pawe	61.18 ± 18.36	2.41 ± 1.32	0.26 ± 0.07	25.47 ± 10.87	31.80 ± 7.59	4.30 ± 1.74
Sherkole	67.07 ± 15.78	3.18 ± 1.47	0.25 ± 0.07	30.22 ± 14.40	28.67 ± 6.68	6.20 ± 2.02
t-value	2.313	3.725	0.841	2.506	1.697	3.894
Sig.	0.022	0.001	0.401	0.013	0.095	0.001

possessed one or more number of branches developed from the main culm node (Figure 2). If the number of branches attached on each seedling was more than one culm node, the branches were attached in alternate positions on the culm node. Once the culm sheath was withered out and fallen off from each culm node, a scar, which is called sheath scar, was left around the culm node. Besides to these morphological structures, culms anatomy further showed that the nodes were solid, while the internodes were semi-solid. Recorded data analysis on seedlings height indicated that the culm height between the two provenances ranged with the minimum and maximum values of 10 and 102 cm, respectively. Pawe provenance scored the minimum culm height of 10 cm and the maximum height of 102 cm. Sherkole provenance had a minimum and maximum culm height of 27 and 100 cm, respectively. Sherkole provenance had better mean value of culm height (67.07 cm) over Pawe provenance (Table 3). The statistical t-test showed that there was a significant difference ($P<0.05$) in culms height between provenances. In contrast to culms height, the number of culms per clump of each polyethylene pot ranged from 2-9. Seedlings in Sherkole provenance developed more number of culms with a mean value of 3.18 than Pawe provenance (2.41). The two provenances also showed significant variation ($t_{(198)}=3.73$, $P=0.001$) in terms of number of culms per clump. But, Pawe provenance had maximum number of culms per clump than Sherkole provenance, which accounted for 9 and 7, respectively.

3.2.2. Root Collar Diameter (RCD). Green house data reported that the minimum and maximum values of RCD were 0.1 and 0.5 mm, respectively between provenances. But, almost no considerable difference in culm diameter growth was observed as compared to culm height. A maximum value of 0.5 mm RCD was recorded in Pawe provenance followed by 0.4 mm in Sherkole provenance. Similarly, a mean value of 0.26 mm in Pawe provenance made better RCD seedlings performance than Sherkole provenance with a mean value of 0.25 mm (Table 3). However, no statistical significant difference ($t_{(179)}=0.84$, $P=0.40$) in RCD was observed between provenances.

3.2.3. Number of Leaves. During the two years *O. abyssinica* seedlings lifespan at green house, the number of leaves in each seedling ranged from 5 to 82. The leaves grew up from the culms sheath and gave rise to the leaf blade. The leaf blade is attached to the culm sheath with a very small petiole. Leaves shaded during dry and hot season (December to February) and new leaves were developed and appeared green thereafter. A total number of 82 and 53 leaves were recorded in Sherkole and Pawe provenance, respectively. By contrast, the minimum number of leaves recorded in Pawe provenance was 10, while it was 5 for Sherkole. A large number of leaves were counted in Sherkole provenance with a mean value of 30.22 ± 14.40 than Pawe provenance (25.47 ± 10.87) (Table 3). The result also showed a significant variation ($P<0.05$) in number of leaves between provenances.

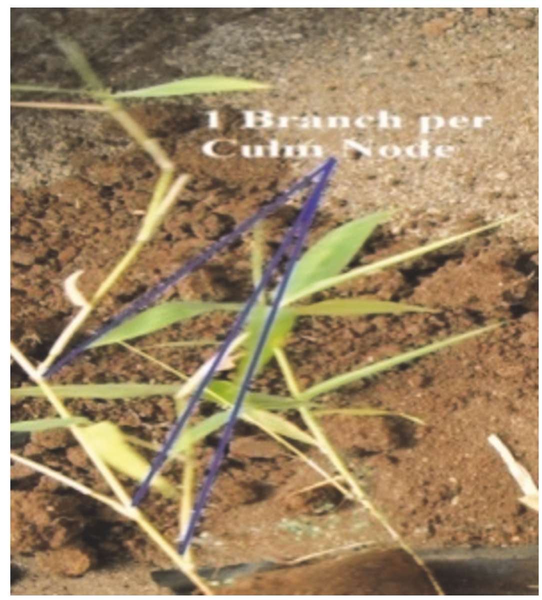

Figure 2: The branching pattern of *O. abyssinica* seedlings at each culm node (**source:** *photo taken by Tinsae Bahru*).

3.2.4. Number and Length of Rhizomes. Practical observation on morphological structure of *O. abyssinica* seedlings was conducted during uprooting of each seedling. Removal of the soil from rhizomes and associated roots indicated that the root system (rhizomes and associated roots) was well established into the surrounding soil within the polyethylene pots. The rhizome bud developed from the mother culm base followed by the development of rhizome from the rhizome bud. Practical observation confirmed that rhizomes were connected to the base of mother culm on opposite side with a

Table 4: Mean values of seedlings Biomass estimation between two *O. abyssinica* provenances (n=30, mean ± SD).

Provenance	Leaf fresh weight (g)	Culm fresh weight (g)	Root fresh weight (g)	Root-to-Shoot Ratio	Leaf dry weight (g)	Culm dry weight (g)	Root dry weight (g)	Root-to-Shoot Ratio
Pawe	2.60 ± 0.98	2.90 ± 1.51	13.63 ± 6.84	2.69 ± 1.15	1.83± 0.68	1.90 ± 0.95	9.30 ± 4.80	2.70 ± 1.35
Sherkole	3.15 ± 1.05	3.03 ± 1.41	12.60 ± 8.42	1.99 ± 0.76	2.41 ± 0.80	2.48 ± 1.11	9.02 ± 6.16	1.77 ± 0.67
t-value	2.122	0.344	0.522	2.784	3.029	2.206	0.194	3.370
Sig.	0.038	0.732	0.604	0.007	0.004	0.031	0.847	0.002

short-neck and finally formed clumps (Figure 1). From each rhizome nodes, 2-7 new rhizome roots were emerged as primary and secondary roots and established in the surrounding soil. At the same time, our observation demonstrated that at the base of the newly emerged Bamboo shoots many adventitious roots (culm roots) developed at the base of the mother culm. Sherkole provenance had slightly more number of rhizomes than Pawe. Such changes in rhizome number also causes a significant variation ($P<0.001$) between provenances (Table 3). Similarly, *O. abyssinica* seedlings possessed longer rhizomes that stretched in length between 9 and 50 cm. But, seedlings from Pawe provenance recorded longer rhizomes than Sherkole provenance. The mean values of Pawe and Sherkole provenances were 31.80 and 28.67 cm long, respectively. Yet, no significant difference was recorded ($t_{(179)}=1.70$, $P=0.095$) in length of rhizome between provenances.

3.3. Effects of Provenance on Total Seedlings Biomass Estimation. Collected data on total biomass estimation of *O. abyssinica* seedlings at laboratory (i.e., fresh and dry weights of shoot and root) were presented in Table 4.

3.3.1. Leaf Biomass Estimation. Leaf biomass comprised the leaves and young buds or twigs after separated from culm and branches of each *O. abyssinica* seedling. The young buds from branches and apical parts of the shoot were also included since they possess chlorophyll due to their green appearance and have a photosynthetic potential. Collected data at laboratory asserted that the weight of fresh leaves from each seedling ranged from 0.77-5.42 g between provenances (Table 4). The oven dried sample, in turn, weighed 0.6-3.88 g. Larger fresh and dry leaf weights were recorded in Sherkole provenance than Pawe provenance. Such result also confirmed by the statistical t-test in that there was variation ($P<0.05$) between provenances in leaves weight before or after the dry oven test. These total mean values of fresh and dry leaf weights of Sherkole provenance were 3.15 and 2.41 g, respectively.

3.3.2. Culm Biomass Estimation. Once the leaves and young buds separated from shoot in each seedling, the culm and branches made ready and weighed together. Analysis of laboratory data reported that the minimum fresh culms weighed 0.57 g, while the maximum was 6.57 g. Similarly, the minimum and maximum dry culms weight ranged from 0.49-5.16 g, respectively. Sherkole provenance had better culms biomass weight with a mean value of 3.03 g for fresh weight and 2.48 g for dry weight (Table 4). But, the variation between provenances was significant ($P<0.05$) for dry culms weight, while there was no such trend in fresh weight samples.

3.3.3. Root Biomass Estimation. Root biomass estimation in this study was based on each seedling underground root system. The root system comprised the mother culm base, culm roots, rhizomes as well as rhizome roots. Data analysis on *O. abyssinica* root biomass estimation indicated that the highest fresh and dry weights were recorded compared with other shoot parts (culms or leaves). The amount of water held in the root system was contributed for this additional weight gain. Accordingly, freshly collected root system weighed the least and the largest values of 3.23 and 47.45 g in *O. abyssinica* seedlings, respectively. The dry root weight also comprised from 2.07 up to 34.52 g weights after dry-oven record. Seedlings of Pawe provenance had higher weight gain with a mean value fresh and dry weights of 13.63 and 9.30, respectively (Table 4). However, this root fresh and dry weight variation was not significant ($P<0.05$) between provenances. Furthermore, the underground *O. abyssinica* seedlings biomass was 68.8% and 65.5% in fresh and dry biomass weights, respectively, out of the total biomass.

3.3.4. Root-to-Shoot Ratio. Root-to-shoot ratio of *O. abyssinica* seedlings is expressed as the ratio of the underground (root) weight to the aboveground (shoot) weight of seedlings as presented in Table 4. It measures the overall health, i.e., the growth and development of seedlings. Laboratory result asserted that *O. abyssinica* seedlings fresh root-to-shoot ratio (2.69 ± 1.15) was lower than the dry ratio (2.70 ± 1.35) for Pawe provenance. But, this ratio was the reverse in Sherkole provenance, where the fresh root-to-shoot ratio (1.99 ± 0.76) was larger than the dry ratio (1.77 ± 0.67). In contrast, both the fresh and dry root-to-shoot ratio of Pawe provenance was higher than Sherkole provenance. This is because of the higher root biomass weight in Pawe provenance as compared to Sherkole.

4. Discussion

A two-year research study at green house on *O. abyssinica* seedlings found out that seedlings were grown up to a height of 102 cm and around 0.5 mm RCD. The seedlings size for field establishment further demonstrated that the average height was 64 cm, which is successfully achieved beyond the recommended value. But, the average RCD was 0.26 mm, i.e., far less than the required size. Previous studies on plantable size of *O. abyssinica* seedlings at nursery reported that its height ranges from 40 to 50 cm [9], while the RCD of sympodial Bamboo seedlings is above 0.5 cm [24, 25]. The pachymorph rhizome type of *O. abyssinica* seedlings found out in this study is similarly reported by earlier researchers [3, 4, 10, 13]. This is because such type of rhizome is characterized by the formation of clumps and has a short rhizome neck emerged from the mother culm base [3, 13]. In addition, earlier studies on sympodial Bamboo reported that this rhizome type is mostly seen in tropical Bamboo [26]. A slightly higher survival rate of *O. abyssinica* seedlings at Pawe provenance (91%) than Sherkole provenance (90%) revealed that the seed sources further contributed to the successful survival rate of seedlings at green house. Former research conducted by [11] assured that Pawe provenance has better seed germination and seed weight than Sherkole provenance. Nevertheless, both provenances further have higher potential in producing viable and vigour seeds [12]. In any case, these two research outputs suggested that provenance variation has some contribution for both producing viable and vigor seeds at laboratory and better survival rate and growth performance of *O. abyssinica* seedlings at green house. This, further, plays a key role in production of best quality and required number of seedlings for intended plantation development goals at field. Such variation might enhance both the early survival and growth performance and hence the adaptation potential of a suitable provenance [27]. Earlier research outputs also support this study, where the variation of provenances has an effect on the seedlings survival rate and growth performances on various tree species [28–30]. This is because species widely distributed in a broad geographical range are generally associated with provenance variation in both morphological and physiological attributes [16, 27]. Savill et al. [16] defined the term provenance as the original geographic source of the seed. As a result, the difference in provenances is associated with a variation in their adaptation ability at a particular area. According to the study this is because there is a limited probability of inbreeding between provenances and thereby causes always genetic variations. Therefore, during plantation development of *O. abyssinica* seedlings selection of provenances to produce high quality and large number of seedlings should be considered so as to maximize the survival rate of seedlings and minimize the mortality rate (up to 10%) of seedlings. This research output is again supported by Mamo and Mihretu [23] as well as Shumi et al. [28], where the long-term yield of plantation per unit area can be affected by the mortality or survival rate of seedlings.

The morphology of *O. abyssinica* seedlings at green house demonstrated that some culms possessed one or more number of branches developed from the main culm node. These branches were attached in alternate positions on the culm node. Such branching pattern on a culm node is an important criterion for Bamboo species identification and taxonomy [26]. The presence of sheath scar in each culm node on *O. abyssinica* seedlings are also similarly mentioned by other related study on Bamboo morphology [31]. Furthermore, the semi-solid feature of culm internodes during the seedling stage is changed to solid culm internodes after maturity [3, 4, 10, 13]. This especial feature makes the species more preferable in construction and other related uses even as compared to the Ethiopian indigenous Highland Bamboo (*Arundinaria alpina* (K. Schum.)). There was almost no considerable difference in culm diameter growth (0.1-0.5 mm RCD) was observed as compared to culm height. This might be due to the absence of cambium and radial tissues in Bamboo [31] unlike stem diameter of trees. As a result, Bamboo undergoes primary growth but not secondary growth [26, 31]. Higher seedlings RCD growth, in turn, might be helpful in better physical support and establishment of the seedlings. Larger culm height and number of culms per clump in Sherkole provenance associated with larger RCD values in Pawe provenance further could be contributed for better physical support and field establishment, survival rate and higher growth performance of seedlings. Some of the pervious works that support this result include Florence [27], Shumi et al. [28], Bahru et al. [29, 30], Alem et al. [32], Andivia et al. [33], Fredrick et al. [34], and Terefe et al. [35]. A large number of leaves were counted in Sherkole provenance as compared to Pawe provenance. Such development of large number of leaves per seedlings is contributed to large surface area for light absorption [36, 37]. This further enhances higher efficiency of photosynthesis within leaves and resulted in higher growth rate of seedlings [36–38]. Therefore, Sherkole provenance is suggested for raising seedlings at green house due to its larger culm height, number of culms per clump, and number of leaves and hence better adaptation potential. Likewise, Sherkole provenance had slightly more number of rhizomes, while Pawe provenance recorded longer rhizomes roots. Such large mass and longer rhizomes and rhizomes roots might increase the surface area for efficient absorption of water and nutrients [39]. It also provides a firm physical support for seedlings as well as a means of vegetative reproduction system [40]. Furthermore, the normal physiological function of fine roots and leaves is directly related [41]. Considering the study this is because the finest roots of a tree are connected to the leaves by an elaborate system of larger transport roots, stems, branches and twigs.

Biomass estimation of leaf weights indicated that almost two-third or 75% of the water retained in *O. abyssinica* seedlings was lost after dried in dry oven. Hence, this study further assured that most of the weight of leaves was occupied by water, which might play a significant role for the process of photosynthesis and transpiration. Consequently, this further enhances higher efficiency of photosynthesis within leaves and resulted in higher growth rate of seedlings [36–38]. Sherkole provenance had better culms biomass weight than Pawe provenance. Nath et al. [42] reported that the aboveground Bamboo stand biomass and carbon storage potential was 121.51 t/ha and 61.05 t/ha, respectively. Out of this, the author reported that the highest stand biomass was produced by culms (86%), branch (10%) and leaf (4%). Finally, 68.8% of underground *O. abyssinica* seedlings was fresh biomass suggested that Bamboo are important in underground high biomass production and carbon sink. Likewise, the total aboveground biomass of *Bambusa bambos* is almost twice that of the *Eucalyptus* clones [43]. The higher productivity, the fastest growth potential and short rotation

Table 5: Provenances of *O. abyssinica* seedlings suitability index evaluation.

Provenance	Scoring out of 10 points										Total scores	Rank
	Survival rate	Height	RCD	No of culms	No of leaves	Rhizome length	No of clustered rhizome	Leaf fresh weight	Culm fresh weight	Root fresh weight		
Pawe	9.1	6.1	0.026	0.24	2.5	3.2	0.4	0.26	0.29	1.4	23.52	**2nd**
Sherkole	9.0	6.7	0.025	0.32	3.0	2.9	0.6	0.32	0.30	1.3	24.47	**1st**

Table 6: Correlation matrix of *O. abyssinica* seedlings growth and Biomass variables for Sherkole provenance (Pearson coefficients, two-tailed, and n = 30).

Variables	Height	RCD	Height/RCD ratio	Rhizome length	R/S Biomass ratio	Seedlings total Biomass	Shoot Biomass	Root Biomass
Height	1							
RCD	.333	1						
Height/RCD ratio	.366*	-.695**	1					
Rhizome length	.207	.279	-.094	1				
R/S Biomass ratio	-.197	-.756**	.657**	.358	1			
Seedlings total Biomass	.616**	.461*	.000	.576**	-.105	1		
Shoot Biomass	.504**	.527**	-.123	.485**	-.201	.805**	1	
Root Biomass	.598**	.409*	.031	.565**	-.067	.987**	.706**	1

**. Correlation is significant at the 0.01 level.
*. Correlation is significant at the 0.05 level.

of Bamboo over the *Eucalyptus* species confirm that Bamboo are a potential promising species for large and small scale plantation development. The fresh root-to-shoot ratio of Pawe provenance (2.48) was higher than Sherkole provenance (2.04). Therefore, the greater root-to-shoot ratio in Pawe provenance could be related to the limited availability of water and nutrients supply to the leaves. As a result, more energy is shifted from the shoot to the roots and thereby the growth and development of the root system becomes more proliferated and flourished deep into the soil. According to Taiz and Zeiger [37] root-to-shoot biomass ratio appears to be governed by functional balance between water uptake by the root and photosynthesis by the shoot. In one hand, a shoot will tend to grow until water uptake by the roots becomes limiting to further growth. In contrast to shoot growth, roots tend to grow until their demand for photosynthesis products exceeds from the shoot supply [36, 37]. But such plant functional balance will be affected by the water deficits in the soil. As the water supply to shoot becomes limited the process of photosynthesis is affected. Eventually, in order to reverse the continuous supply of water to leaves more energy is allocated to the root system so as to enhance further root growth into deeper soil for the absorption of enough water [36, 37, 44, 45].

In general, provenance variation on early survival rate and growth performance of *O. abyssinica* seedlings was evaluated using suitability index (Table 5). Accordingly, Sherkole provenance (24.47) had better suitability index than Pawe provenance (23.52) for raising seedlings at green house. This study was in agreement with a research carried out by Mamo and Mihretu [23] on provenances of *Juniperus procera*. Therefore, Sherkole provenance is promising to select as seed sources and raising seedlings.

At the same time, considering its suitability for raising quality seedlings at green house, Sherkole provenance growth and Biomass parameters were further evaluated for the correlation analysis (Table 6). With this, seedling height had a strong positive correlation with seedlings total Biomass (r = 0.616; $p < 0.01$). In turn, the highest significant negative correlation was observed between seedling RCD with both root-to-shoot Biomass ratio & height to RCD ratio (r = -0.756&-0.695; $p < 0.01$). Meanwhile, shoot Biomass & root Biomass; seedlings total Biomass & rhizome length as well as root-to-shoot Biomass ratio & height to RCD ratio were also strongly correlated to each other ($p < 0.01$). On the contrary, except for height and root-to-shoot Biomass ratio and RCD & seedlings total Biomass, which had a significant correlation at $p < 0.05$, there was no significant correlation ($p < 0.05$) between other morphological variables. Collectively, our result was closely consistent with Tian et al. [46], who reported that seedling height has a highly significant positive correlation ($p < 0.01$) with other morphological and Biomass variables. Therefore, such correlation of morphological variables might be used to evaluate seedling quality at green house and thereby forecast its performance at field.

Based on this result, linear regression equations were developed for six main variables that strongly correlated to each other (Figure 3). The equation was written as y=a+bx, where y is a dependent variable, x is a predictor variable for the linear regression model, a is the y-intercept at $x = 0$ and b is the slope of the regression equation. Consequently, the highest values of coefficient of determination (R^2) was

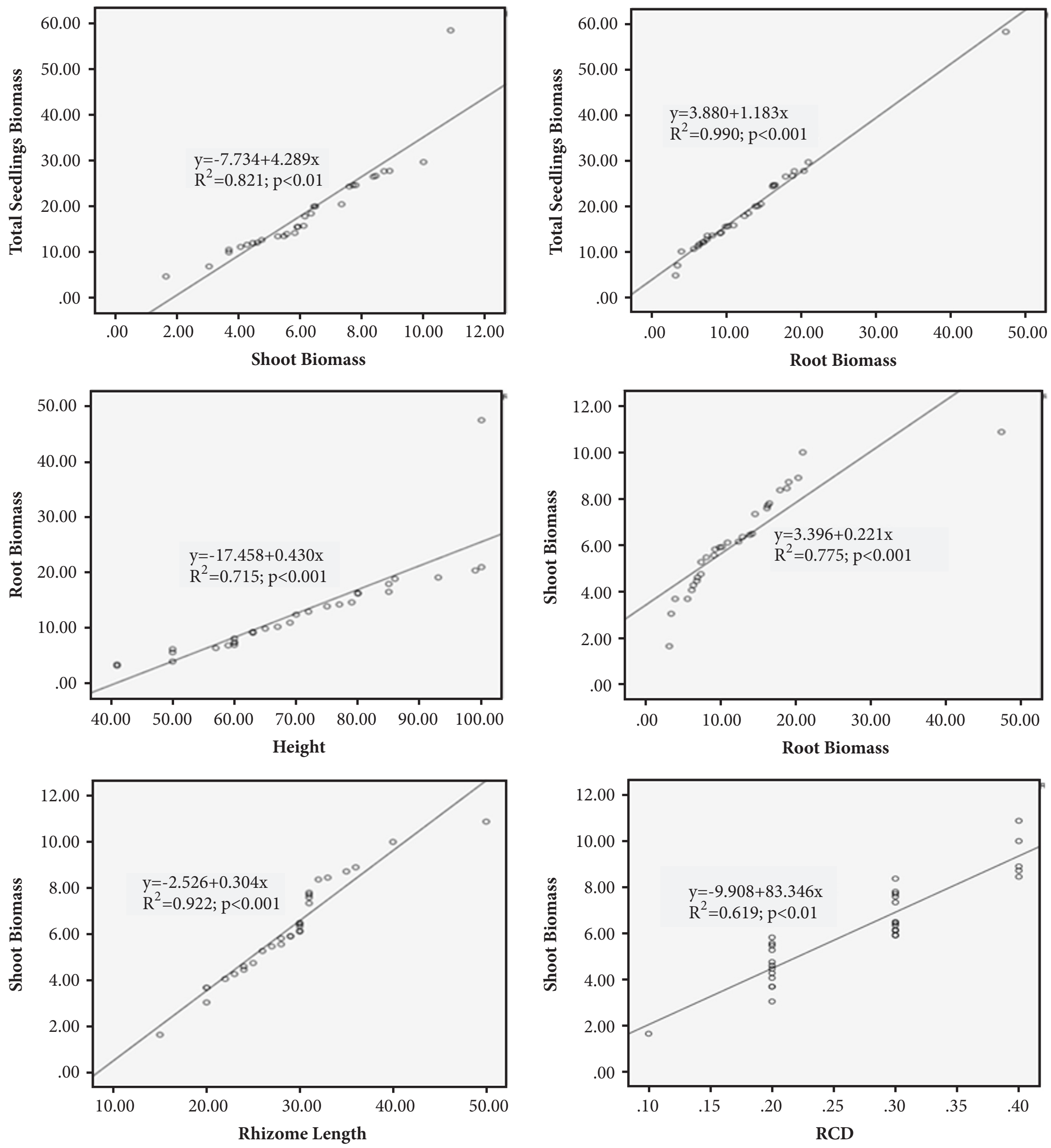

Figure 3: Relationship between *O. abyssinica* seedlings growth and Biomass variables and the developed linear regression equations and coefficient of determination (R^2) that indicated the strength of regression model.

recorded in the developed linear regression models (R^2=0.715 to 0.990), which means at least 71.5% of the total variation in the dependent response variable was explained by the linear regression model and hence the strength of the model. Moreover, the larger correlation coefficient (R=0.619 to 0.995) and Beta values (0.787 to 0.995) further indicated the strong linear relationships between the growth and Biomass variables. The strongest linear correlation among the six pairs of variables was illustrated by root Biomass with total seedlings Biomass. On the contrary, shoot Biomass and RCD and the weakest linear association among the variables. At the same time, seedlings height had a relatively strong association with root Biomass, while RCD had strong correlation with shoot Biomass. Shoot and root Biomass in turn, had strong association with other variables. Therefore, the strong linear association of height and RCD with all other variables assured that seedling quality at green house was evaluated only with height and RCD data without considering other variables, which is more cost effective and time saving process.

5. Conclusion and Recommendation

The present study found out that Pawe provenance had higher survival rate (91%) than Sherkole provenance (90%). Therefore, the insignificant provenance variation further suggests that both provenances (Pawe and Sherkole) are recommended for raising large number of *O. abyssinica* seedlings at green house with higher survival potential. Except higher RCD, rhizomes length, fresh and dry roots weights, and higher seedlings parameters were recorded in Sherkole provenance. Biomass estimation for both provenances further indicated that weight of fresh leaves, culms, and rhizome system ranged from 0.77 to 5.42, 0.57 to 6.57, and 3.23 to 47.45 g, respectively. Nevertheless, significant variation ($P<0.05$) between provenances was observed in RCD, rhizomes length, weight of fresh culms, and fresh & dry root system. Fresh root-to-shoot ratio (1.99 ± 0.76) was larger than the dry ratio (1.77 ± 0.67) for Sherkole provenance. But, both the fresh and the dry root-to-shoot ratio of Pawe provenance were higher than Sherkole provenance. In Sherkole provenance, seedling height had a strong positive correlation with seedlings total Biomass ($r = 0.616$; $p < 0.01$). However, the highest significant negative correlation was observed between seedling RCD with both root-to-shoot Biomass ratio & height to RCD ratio ($r = -0.756$&-0.695; $p < 0.01$). Overall, Sherkole provenance had better suitability index (24.47) than Pawe provenance for raising seedlings at CEE-FRC green house. However, Pawe provenance is further recommended as a promising alternative for seedlings production especially if there is a scarcity of seeds from Sherkole provenance. Seedlings growth parameters (height and RCD) were positively and significantly correlated with Biomass variables and hence could be considered as better evaluation criteria for seedling quality at green house. Lastly, this green house result might be not applicable at field establishment of *O. abyssinica* seedlings. Therefore, the provenance trial should be further carried out at field to evaluate the establishment, growth performance as well as adaptation potential and thereby select better provenance for future plantation development.

Data Availability

The data that support the findings of this study are available from Central Ethiopian Environment and Forest Research Center (CEE-FRC)/Ethiopian Environment and Forest Research Institute (EEFRI) but restrictions apply to the availability of these data, which were used under license for the current study, and so they are not publicly available. Data are however available from the corresponding author (Tinsae Bahru) upon reasonable request and with permission of Central Ethiopian Environment and Forest Research Center (CEE-FRC)/Ethiopian Environment and Forest Research Institute (EEFRI).

Conflicts of Interest

The authors declare no conflicts of interest.

Authors' Contributions

All authors had their own intellectual contribution towards the implementation of this research work and eventually to produce the full manuscript write up. Tinsae Bahru is the corresponding author of this manuscript. He mainly commented the project activity during the implementation of the activity, seed collection, processing and handling, established the experimental layout at laboratory and green house, data collection, entry, and analysis, wrote the full manuscript, and submitted the manuscript to the Journal and eventually incorporating all the given constructive comments by the reviewers. Berhane Kidane and Yigardu Mulatu were involved in writing the project activity.

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