SJIF IMPACT FACTOR: 4.402 CRDEEPJournals
International Journal of Life Sciences Demelash A. Ayana et.al., Vol. 4 No. 4 ISSN: 2277-193x
International Journal of Life Sciences Vol. 4. No. 4. 2015. Pp. 221-231

Full Length Research Paper

Seed Characteristics and Seed Production potential of *Oxytenanthera abyssinica* in Benishangul Gumuz Regional State, Northwestern Ethiopia

*[1]Demelash Alem Ayana, [2]Abdella Gure and [3]Kassahun Embaye

[1]*Department of Natural Resources Management, Debre Markos University, P.O. Box 269, Debre Markos, Ethiopia.*

[2]*School of Forestry, Wondo Genet College of Forestry and Natural Resources, Hawassa University. P.O. Box 128, Shashemene, Ethiopia.*

[3]*Department of Environmental Sciences and Sustainable Development, Hope College of Business, Science and Technology, P.O. Box 12382, Addis Ababa, Ethiopia.*

***Corresponding author: Demelash Alem Ayana**

Abstract

This study was conducted in Pawe and Bullen districts of the Benishangul Gumuz Regional State, Ethiopia to establish the seed production potential, the nature of seeds and the effect of sites and position of fruit on the culm on seed production and seed nature of O. abyssinica seeds. Bamboo growing areas were stratified in to four land use types as protected, free access, grazing land and homestead bamboo. In each landuse type, one central or nearest to central clump was selected and three central culms in each clump were considered for fruit collection. The fruiting portion of the culms was equally divided in to three equal parts. The two fruit collection sites and fruit-collection heights (top, middle and bottom fruiting portion of the culm) were treated as factors, to discover their effects on the seed production and seed characteristics of the species. The fruits were collected from the surrounding and investigations on seed germination, number of seed bearing fruits per aggregate fruit and their percentages, purity percentage of seeds, number of days taken to accomplish germination, number of days taken for 50% germination and number of days required for achieving germination energy and other parameters were conducted. The study revealed that there was statistically significant difference between the study sites in most of these parameters (α=0.05). All the parameters but the number of days required for 50% germination of seeds did not show statistically significant difference among fruit collection heights on the culm. All the parameters studied did not show significant differences due to fruit collection sites × fruit collection height interaction effects (α=0.05). The study also revealed that O. abyssinica had low seed production, high germination percentage and germination speed. It is possible to collect seeds on the culm, regardless of sites and fruit collection heights as most of seed quality measures were found almost the same along the different fruiting portion of the culm. Seed setting stage is critical for the continuity of the species in the area. Therefore, management and conservation measures should be done.

Keywords: *Fruit collection height; Germination; Oxytenanthera abyssinica; Seed characteristics; Seed Purity; Seed production; Seed quality.*

Introduction

Highland bamboo (*Yushinia alpine)*, and the lowland bamboo (*Oxytenanthera abyssinica)* are the two species of bamboo in Ethiopia. *O. abyssinica* is prominent in river valleys and on the escarpment of western part of the country such as the Benishangul Gumuz Regional State (Ensermu *et al*., 2000). Bamboo has significant contribution for the socio economic development of a nation (Baghel *et al*., 1998; Kumar *et al*., 1998; Perez *et al*., 1998; Sharma *et al*., 1998; Kumar & Sastry, 1999); for environmental protection (Kumar & Sastry, 1999; Bystriakova *et al*., 2004); for different construction purposes and animal fodder, human food, as an agroforestry species (Maoyi, 1994; Christanty *et al*, 1997) and others.

In Metekel Zone of the Benishangul Gumuz Regional State, most of the natural stands of *O. abyssinica* forest is disturbed and not in their natural condition. Protection and development endeavors afforded to this species are negligible. At present the bamboo is flowering gregariously which may be accompanied by the death of the species, which further may result in ecological crises (John & Nadgauda, 2002). Unless the species is assisted by artificial propagation, its survival will be under question (Embaye, 2000; Ensermu *et al*., 2000).

Though, *O. abyssinica* propagates sexually and asexually (Azene *et al*., 1993; Dwivedi, 1993; Kassahun *et al*., 2003), offset method of vegetative propagation was found difficult for large-scale plantations (Kassahun, 2003). The origin and age of the rhizome could not be ascertained in the case of large-scale collection (Saharia & Sen, 1990). Plants raised by vegetative propagation may be disastrous if the age of the parent plant is old. Hence, if seed is available, propagation by seed should be given a priority wherever that is possible

(Kassahun, 2003). But little is known about the seed characteristics of the species and hence, investigation of the seeds of bamboo is important (Anantachote, 1988). This study was conducted to generate information on seed characteristics of *O. abyssinica*, which includes determination of the seed production potential; seed germination; effect of site and fruit collection heights of the culm on seed production and seed quality parameters.

Materials and Methods

Study Area Description

Seeds used for the study were collected in a population of *O. abysinica* in Bullen and Pawe special districts of Benishangul Gumuz Regional State, Ethiopia, Southwestern Ethiopia (Fig. 1). The mean annual temperature at the seed collection districts were 1555.1mm (Pawe Meteorological station) and1979.5mm (Metekel Zone department of agriculture) for Pawe and Bullen respectively. Pawe lies between $36^0$20' to $3636^0$32' E and a specific area in Bullen where fruit collection was done is situated at $10^0$0' N and $35^0$59'. The germination experiment was conducted in Pawe Agricultural Research Centre (PARC), situated at $11^0$09' N latitude and $36^0$03' E longitude having an elevation of 1050 m a.s.l. Pawe special district has topography of 4% mountain, 22% undulating and 74% plain and that of Bullen district is 5%, 35% and 60% respectively (Metekel Zone Department of Agriculture, personal communication).

Pawe special district has an altitude of 980–1050 m a.s.l. Bullen district has altitude of 1500-1750 m a.s.l According to Engda (2000), the surroundings of Metekel Zone have a wide climatic range within M_1 and SH_1, (hot to warm moist lowlands and hot to warm sub humid lowlands). The major soil groups are generally identified as Nitosols, Vertisols and fluvisols (UNDP/ECA, 1998).

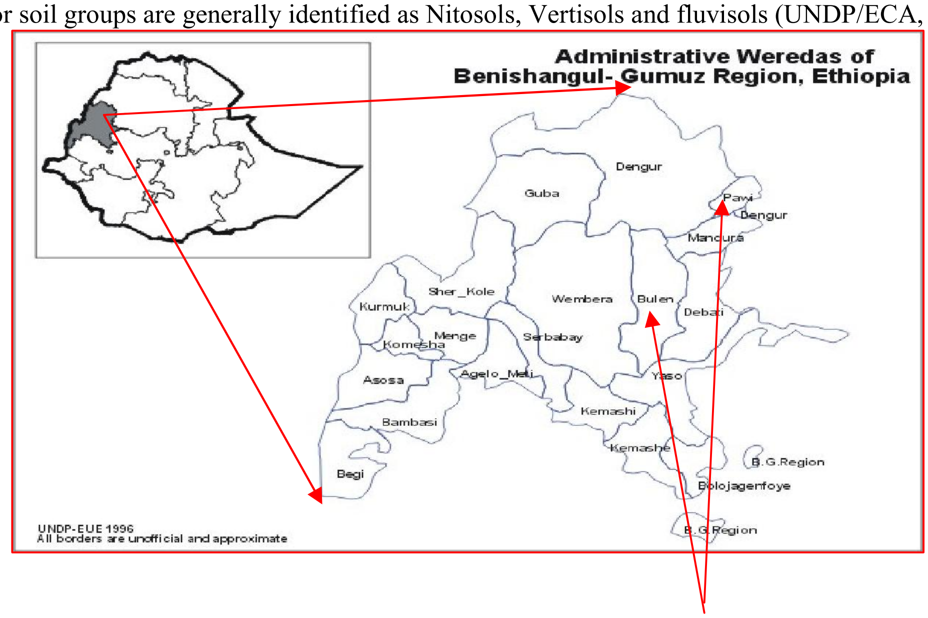

Fig. 1: The location of the study sites

Sampling Technique and Experimental Design

Bamboo growing areas in the study districts were stratified in to protected area, free access natural forest, grazing land and homesteads. From each land use type, one central or nearest to central clump was selected. Three central culms from each sample clump were considered and fruiting portion of the culms was divided into three equal parts. Fruits of each portion were harvested and allowed to dry for a month in open air under shade. Ten aggregate fruits were selected randomly, separated in to single fruits. The remaining aggregates fruits in each fruit collection heights were then processed to take sample for seed characteristics measurement. A split-plot design with randomized complete block design structure was used. Four landuse types (protected forest, natural but accessed forest, grazing land and homesteads) were used as blocks. The locality with two levels (Pawe and Bullen districts) was treated as main plot and three fruit collection heights on the culm (one-third, two-thirds and three-thirds, starting from the top fruiting portion of the culm) were used as the sub-plots.

Purity Test

Seed purity was determined by taking 10 g from each collection height and location. The seeds were then separated into pure and impure seeds. Purity percentage was expressed as:

$$Purity = \frac{weight\ of\ \ pure\ seed\ (g)}{weight\ of\ \ working\ sample\ (g)} * 100\%$$

The pure seeds were stored in a cold room until they were sown so that seeds will not loss their viability (Dwivedi, 1993; Jamaluddin *et al.*, 1998).

Seed Weight Determination

Eight random samples of one hundred seeds from each site and fruit collection height were drawn and weighed. The average weight of the samples was used to determine the weight of one seed. From this weight, the number of seeds per g and per kg was calculated (FAO, 1985). During sample weight determination, the seeds had average moisture content of 6.5% when seed weight was determined. .

Germination Test

Before conducting this test, the germinating medium, *i.e.* petridishes (9.5 cm diameter) with moist blotting paper, was set up in the laboratory at Pawe Agricultural Research Center (PARC), at a mean daily temperature and relative humidity of 26–30 °C and 35–46%, respectively. Germination test was carried out using four replicates of one hundred seeds. For convenience, each replicate was divided into 50 seeds per petridish (Bonner, 1974). Seeds were sown uniformly. No seed treatment was applied; bamboo seeds do not have dormancy (Kassahun *et al*., 2003). Young & Augspurger (1991) also state that semelparous plants (similarity is a distinct life history, in which a massive reproductive output is directly associated with pre-programmed whole-organism death) such as *O. abyssinica* have little or no seed dormancy. Daily data were collected (Gulzar & Khan, 2001). Abnormal seedlings, seeds infected with fungus, and ungerminated seeds were considered as non-viable. When no further germination had appeared, the total number of germinated seeds for each treatment/ factor combination was added, to determine the germination percentage of bamboo seeds (Palzer, 2000). Ungerminated seeds were inspected for viability and for the cause of any seed defect. From the data collected, the other required germination parameters were determined.

Germination energy was determined by recording the germination data until the number of germinated seedlings declines or falls off (Schmidt, 2000). Germination energy was determined (1) by taking data up to the day of peak germination; (2) by taking data until daily germination falls to less than 25% of the peak germination (3) the number of days required to attain 50% of the germination capacity.

Germination value was computed as follows (Djavanshir & Pourbeik, 1976):

$$GV = \left(\frac{\sum DGS}{N}\right) * \frac{GP}{10}$$

Where;
GV= Germination value
GP= Germination percent at the end of the test
DGS= Daily Germination Speed, obtained by dividing the cumulative germination percentage by the number of days since sowing.
$\sum DGS$ = *The total obtained by adding every DGS figure obtained from the daily count*
N= the number of daily count, starting from the date of first germination
10= Constant

Germination speed, which is expressed as peak values and is the maximum mean daily germination (cumulative percentage of full seed germination divided by the number of days elapsed since sowing date) reached at the time during the period of the test. The value was calculated from the germination values for the germination test (1985),

Data Analysis

Prior to analysis, data were checked for normality and homogeneity assumptions and the mean percentage and count data were transformed using Arcsine and square root transformation respectively to normalize the data for analysis of variance. However, the means were compared on untransformed (original) data. ANOVA was performed on all the data using SAS software (1999-2001, SAS Institute Inc., USA). All statistical comparisons were considered significantly different at $p<0.05$. For mean comparisons we used the least significance difference (LSD).

Results

Observable Seed Characteristics

The seed of lowland bamboo (*O. abyssinica*) within the fruit is positioned in such a way that its radicle lies towards the base of the fruit. The seeds were covered by 4–5 alternative glumes (seed coverings). The length of the glumes increases from the outermost to the innermost layers. The embryo lies loosely attached at the broader side of the seed. The seed has also a permanent stigma on the opposite side of the embryo (Fig.2).

Measurable Seed Characteristics

None except the number of days required for 50% germination showed statistically significant difference among the positions of fruit on the culm. There was no also statistically significant difference in any of the variables studied between study sites and among fruit collection height interactions (Table 1). Among the variables, the only ones that did not show statistically significant difference among landuse types were the number of seeds per kilogram, number of days required for germination accomplishment, germination energy and number of days required to achieve that germination energy (Table 1).

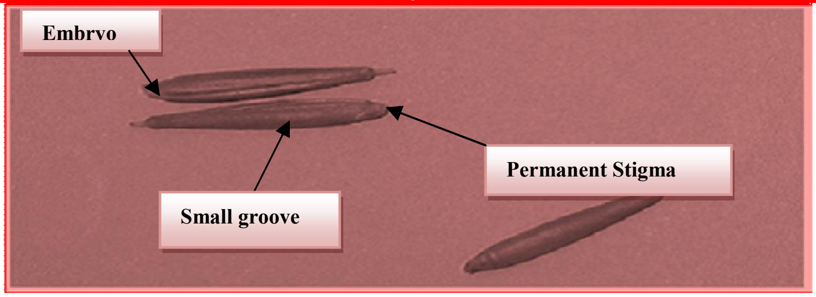

Fig. 2 *O. abyssinica* seeds

Table 1: ANOVA studied parameters on *O. abyssinica* seeds

	Mean squares				
Variables	**Land use**	**Loc**	**Cht**	**Loc*Cht**	**Error**
DF	3	1	2	2	12
1000 seed wt.,	264.49*	77.04 NS	30.97 NS	91.95 NS	72.91
Seeds per kg.	4590173.15 NS	600717.04 NS	534908.04	1971611.54 NS	1644591.9
Purity (%)	135.75**	84.98*	0.01 NS	4.24 NS	14.76
Germination (%)	128.821**	0.02535 NS	34.647 NS	26.910 NS	19.56
Viability (%)	189.22**	88.17 NS	33.17 NS	26.17 NS	22.39
DG	2.11 NS	66.67**	0.54 NS	4.04 NS	3.35
DFPG	0.56*	6**	0.54*	0.13 NS	0.11
GE	75.17 NS	522.67 NS	1.13 NS	24.54 NS	172
DGE	0.38 NS	12.04**	0.13 NS	0.29 NS	0.32

**, ** Significance at α = 0.05 and 0.01 respectively, NS= non-significant, DF=degrees of freedom, Loc=Location, Cht=fruit collection portion of the culm, Loc*Cht= location and collection height interaction, DG=days to accomplish germination, DFPG=days required for 50% germination, GE=Germination energy, DGE=days to achieve germination energy.*

Seed Purity

There was a statistically significant difference in the percentage purity of seeds between study sites (p=0.0335) and among landuse type (p=0.0020) but not among collection height (p>0.999) and location with collection height interaction (p>0.755). There was also little difference in the purity percentage of seeds among fruit-collection heights. The maximum value (90.8%) was recorded in Pawe at the top fruiting portion of the culm. The second and third maximum values were also recorded in the same locality in the middle and bottom fruiting portion of the culm. The overall average across locations and fruit collection heights of the culm showed that *O. abyssinica* in the study areas had percentage seed purity of 88%.

Seed Weight

There was no statistical significant difference in the mean values for the thousand-seed-weight of *O. abyssinica,* that could be ascribed to location (p > 0.3242), fruit collection heights on the culm (p>0.663) and their interactions (p > 0.3183). Landuse types showed statistically significant difference in the variable considered (p=0.0452). The maximum thousand-seed-weight (95.2g) occurred in the bottom fruiting portion of the culm in Bullen district. In Pawe, the maximum thousand-pure-seed-weight (tpsw) was observed in the top fruiting portion of the culm, followed by the middle and bottom portions, with the value of 85.96g and 83.81g, respectively (Table 2). Bullen showed a higher thousand-seed-weight than Pawe. When the data for this variable are averaged for each fruit collection height across the two study districts, the top, middle and bottom fruiting portion of the culm showed a thousand-seed-weight of 85.93g, 86.24g and 89.48g and the number of seeds per kg was 11886.6, 11792.00 and 11399 respectively. The overall average across the two study districts and among the three fruit collection heights was 11692.54 seeds per kilogram and Tpsw of 87.22g.

Table 2: Mean value of thousand-seed-weight and number of seeds per kg

Fruit collection heights	**Location**			
	Pawe		**Bullen**	
	1000seed weight (g)	Number of seeds per kg	1000seed weight (g)	Number of seeds per kg
Top	86.51	11691.25	80.6	12082.00
Middle	85.96	11736.25	86.52	11847.75
Bottom	83.81	12124.75	95.16	10673.25
Average	85.43	11850.8	89.01	11534.3

Seed viability

There was no statistically significant difference in the viability percentage of seeds between location (p>0.0706), among fruit collection portion of the culm (p>0.2661) and their interactions (p>0.3438), while there was statistically significant difference among landuse types (p = 0.0027). There was a slight absolute difference in the parameter due to the studied source of variation, where the maximum value (95.3) and the minimum value (86.8) observed at Pawe in the top fruiting portion of the culm and at Bullen in the bottom fruiting portion of the culm respectively. In location wise, Pawe had higher (91.8) seed viability percentage than Bullen (87.9). The overall viability percentage of *O. abyssinica* seeds was 89.8.

Germination Percentage, Germination Value and Germination Energy

Germination Percentage

There was no statistically significant difference in the germination percentage of seeds between study sites (p>0.9719), among fruit collection heights on the culm (p>0.2118) and their interactions (p>0.2898). Landuse types showed highly statistically significant difference in the germination percentage of seeds (p=0.0079). *O. abyssinica* seeds did not show much difference between study sites and among fruit collection heights (Fig. 3). But the number of days, taken to accomplish germination although not significant varied between sites (Table 1).

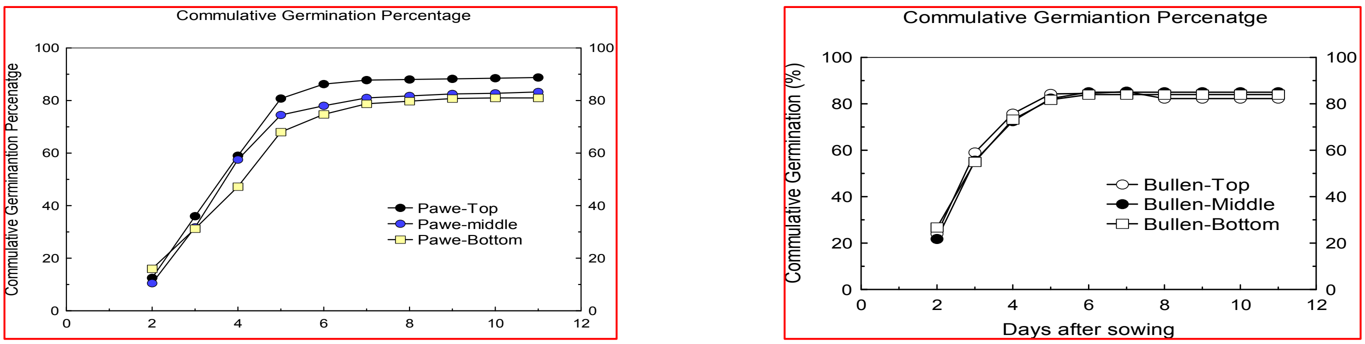

Fig. 3: Cumulative Germination Percentage of *O. abyssinica* seeds at each study site and fruit collection heights

The overall average across the two study districts showed that the germination percentage of seeds in the study area is about 84.5%. With regard to the effect of location**,** the two study districts showed very similar germination percentage (84.3% and 84.7% for Pawe and Bullen respectively). When the data were averaged for the three collection heights, the top, middle and bottom fruiting portion of the culm had germination percentage of 87%, 84.13 and 82.5% germination percentage respectively (Fig. 3).

Germination Values

The highest germination value (135) recorded at Bullen and the lowest value (85.13) occurred at Pawe, both in the bottom fruiting portion of the culm. At Pawe and Bullen the highest germination values were found in the top and bottom fruiting portion of the culm with the value of 100.98 and 134.99 respectively. When collection heights alone were considered top fruiting portion of the culm had higher germination value (117) followed by the middle and the bottom, which had almost equal germination values. The overall average across locations and the fruiting portion of the culm showed that *O. abyssinica* seeds have a germination value of 112. With regard to collection height, the maximum value was recorded in the top fruiting portion of the culm in Pawe location, while in Bullen, all the collection heights showed almost similar germination value. The highest value was found in Bullen at bottom fruiting portion of the culm. On overall *O. abyssinica* seeds have a germination value of 118.4±8.3.

Germination Speed and Energy

O. abyssinica seeds, which were collected at Bullen showed a higher speed of germination and lower energy period than those, which were collected in Pawe. The highest germination speed (19.7) was found in the top portion of the culm, followed by the middle (18.5) and bottom (18.3), with an energy period of three days for the three fruit collection heights at the same location (Bullen). The speed of germination for seeds, which were collected from three collection heights at Pawe were lower than all the three collection heights in Bullen. The speed of germination for seeds collected from three collection heights at Pawe was lower than that at Bullen. In terms of the energy period, seeds collected from Bullen germinated within here days for all three fruit collection heights (Table 3).

Table 3: Germination speed of *O. abyssinica* seeds

Location	Fruit collection heights		
	Top	Middle	Bottom
Pawe	16.15 (5)	14.9(5)	13.6(5)
Bullen	19.67(3)	18.5(3)	18.33(3)

Note: Numbers inside brackets are days taken to achieve the corresponding germination speed.

Germination energy of *O. abyssinica* seeds did not show statistically significance difference between study site (p = 0.1068), among fruit collection heights (p = 0.9935), among the landuse types (p = 0.7306) and study site and collection height interaction (p=0.8685). The number of days taken to achieve this germination energy was significantly different only between the study sites (p< 0.001). When germination energy of *O. abyssinica* seeds was taken up to the date of peak germination, GE, the highest germination energy (68) was observed at Pawe, in the bottom fruiting portion of the culm, and the lowest value (36) was observed in the same location in the top fruiting portion of the culm. This peak value occurred within three days after sowing, while the highest value in Bullen was attained five days after sowing. In the case of Bullen, all of the peak values at the three collection heights occurred within three days after sowing (Table 4).

Table 4: Germination energy of *O. abyssinica* seeds for each study district and fruit-collection heights

Fruit collection heights	**Location**					
	Pawe			Bullen		
	GE1	GE2	GEP	GE1	GE2	GEP
Top	36(3)	80.75(5)	4	59(3)	84.25(5)	3
Middle	57.5(4)	74.5(5)	4	55.5(3)	82.25(5)	3
Bottom	68(5)	74.75(6)	5	55(3)	81.75(5)	3

Note: GE1 is the germination energy taken up to the date of peak germination; GE2 is the germination energy taken as lasting until daily germination falls to less than 25% of the peak and GEP is the germination energy period, which is the number of days required to attain 50% of the germination capacity, the shorter the period being the greater the germination energy. Numbers in brackets indicates the number of days taken to achieve the corresponding germination energy.

In general it was found out that the bamboo seeds have fast germination speed. Within two days after sowing they germinate and show essential plant structures and the majority of seeds germinate within five days (Fig.4).

Fig. 4: Germinating *O. abyssinica* seeds
A: After two days, B: after five days, C/ After 10 days, D and E/ seedling essential structures (after ten and five days respectively).

Seed production potential of the Species

Despite the fact that *O. abyssinica* has lower proportion of seed bearing fruits per sample fruits, it has the potential to produce large quantities of seed and to be used for large scale plantation establishment because of the gregarious nature of the species. Taking number of seed per kilogram, germination and purity percentages of *O. abyssinica* seeds as 11693, 84.54 and 89.83% respectively, it would be possible to produce 8879.58 seedlings from a kilogram of *O. abyssinica* seeds which is collected directly from fruits but not purified. If the purification is done for the species, from a kilogram of pure seed, about 9884.88 seedlings could be produced. Again, taking 5-10% nursery and other losses, it is possible to produce 7991.62 to 8435.6 seedlings from a kilogram of *O. abyssinica* seeds.

The percentage by weight of *O. abyssinica* seeds from a sample of air dried fruits was 23.3% and the percentage by weight of seed bearing fruits from air-dried *O. abyssinica* fruits was found to be 36.2%. From the total air-dried weight of seed-bearing fruits about 64.6% is accounted for by seeds and the remaining (35.4%) is the weight of seed coverings (glumes). It was also found out that the number of fruits per kilogram of air dried fruits was 21607±1463.61. Therefore, a kilogram of air-dried fruits can give about 362g seed-bearing fruits of which about 233.85g are accounted for by seed component and the remaining (128.15g) is the weight of glumes. Thus, it is possible to conclude that from a kilogram of air dried fruit of *O. abyssinica* can yield 2734± 81.85 seeds or 2652.56-2816.26 seeds.

4. DISCUSSION

The absence of statistically significant difference between the sites in many of the parameters studied may be because the two study sites do not exhibit major agro-ecological differences *O. abyssinica* grows in areas with altitudinal range of 1100-1700 m above sea level (Ensermu *et al*., 2000). But the altitudinal range in the case of this study is 1020-1420. A significant difference in the purity percentage of *O. abyssinica* seeds with location, but not with the position of fruit on the culm. This difference among sites might be attributed to the differences in the extent of seed defects. The higher occurrence of shrivelled and fungus-attacked seeds in Bullen district than in Pawe may be the reason for the higher purity percentage of seeds at Pawe. Research findings in this regard are scanty; hence it was not possible to make comparisons. The higher occurrence of fungus-attacked seeds in Bullen may be due to the high amount of rainfall than in Pawe. Fungus development especially damping-off disease is more common where there is high moisture. Moreover, the area might have favored the development of seed borers. They might have development of seed borers from previous year's seed production.

The absence of significant difference in the thousand-seed-weight of *O. abyssinica* seeds with fruit-collection height on the culm and between the study sites disagrees with many research findings. For example, a study conducted on *Pinus sylvestris* showed that the mean thousand-seed-weight was lower in the uppermost 2 m of tree crowns than lower in the crown (Karlsson, 2000). In most species, seed size is correlated with seed weight, hence the variation in seed size. A study conducted by Marchelli1 & Gallo (1999) showed that seed weight was significantly different among populations of *Nothofagus nervosa.*

The absence of significant differences in seed weight between the study sites and fruit-collection heights on the culm might be attributed to lack of difference in the flowering order of *O. abyssinica,* because of the gregarious flowering nature of the species (Dwived, 1993). Had there been an order of flowering in *O. abyssinica* culms the study result would have agreed with Fang *et al*., (2004) findings where it was reported that plants within the peak flowering period had heavier seed than those that flowered earlier in the season.

There was no significant difference in the percentage seed viability of *O. abyssinica* seeds between study sites and among the fruiting portions of the culm. However, the absolute value was higher in the seeds collected from Pawe. This slight difference in seed viability among the three fruiting portions of the culm may be due to the ageing of the seeds; since it was about a month time from fruit collection to germination test, most bamboo seeds have low viability period (Sharma *et al.*, 1998). The effect of position on the crown, even in higher plants, has no clear effect on the viability of seeds (Karlsson, 2000). Since there is few research findings in this regard, more comparisons were not possible.

Seed Germination

Germination percentage

The average germination percentage of *O. abyssinica* seed was 84.5%, which is within the range of 75–95% reported by Kassahun (2003). The time taken to accomplish germination was 11 days, which is in agreement with the results of Kassahun (2003), although the germination medium in that case was soil, andis also close to the findings ofDwived (1993), which stated the germination time of bamboo as 5–10 days. The time taken to start germination was two days from sowing, but four days according to Kassahun (2003). This variation may be due to differences in the medium of germination and in the environmental factors between the areas where the two studies were carried out. The fewer days, required to accomplish germination in Pawe conditions may be due to the high temperature of the area. The effect of temperature in germination of seeds is well documented in many species such as *Helianthemum* species (Pérez-Garcí & Gonzíez-Benito, 2005). The similarity in the germination percentage of *O. abyssinica* seeds collected from the two study districts may be a result of similarity in most of the seed-quality measurements, which may have been caused by similarity in thecharacteristics of the two areas.

The absence of a significant difference in the germination percentage, associated with position within the fruiting portion of the culm, might depend on the similarity of most seed-quality measurements, such as purity percentage, viability percentage and thousand-seed-weight along the height of the culm. Had there been a difference, especially in thousand-seed-weight (which of course reflects seed size), the study would have revealed it, and would have agreed with many research findings which demonstrate that variation in seed germination is due to seed weight and size. But there are studies that indicate variation in seed germination due to weight and size (Khan *et al*., 1999; Muhammad & Amusa, 2003; Moravcová *et al*., 2005).

Comparatively lower germination percentage of *O. abyssinica* seeds than previous studies might be due to seed quality deterioration. Seed quality deterioration usually commences at physiological maturity and continues during harvest, processing and storage, which in turn are governed by the genetic constitution, environmental factors during seed development and storage conditions (McDonald, 1999).

Germination Energy and Value

There was also no significant difference in the germination energy, and the number of days required to achieve this germination energy, among the positions of fruit on the culm, and between the study sites. This result is contrary to Negash *et al*., (2006) research findings, where it was found out that longitude of seed origin had a fairly good correlation with the rate of germination. It is stated that such correlation is expected in a material, which is autochthonous; *i.e*. from a population of tree/plant which is known to have naturally regenerated without human interference since primary colonization (Negash *et al*., 2006). The absence of difference in germination of *O. abyssinica* between study sites and among fruit collection height of the culm may be correlated to seed weight, which is also related to seed size, as there was no significant difference in this and other seed quality measurements. But the number of days taken to achieve 50% germination, which is a measure of germination energy, was higher at the bottom, followed by the middle and the top fruiting portion of the culm.

Information in the germination of bamboo in general, and of *O. abyssinica* in particular, is scanty; hence it was not possible to make comparisons for this research finding. So information for other types of plants was reviewed. The results of previous studies in other plants were not consistent. For example, Malcolm *et at*. (2003) stated that larger seeds perform betterbecause of the greater amount of nutrients available to the developing embryo. The same study also indicated that heavier seeds have a higher germination percentage and germinate faster. Al Karaki (1998) showed that the rate of water uptake by lentil seeds from solutions of different water potential was higher for larger than for medium or smaller seeds and contributed to higher germination. However, Jun & Yunzhi (1996) stated to the contrary that larger seed might have a thicker seed coat, which limits the ability of the seed, to absorb water; hence results in lower germination speed. The study conducted by Eriksson (1999) showed that in *Convallaria majalis* the timing of germination was not related to seed size. In the case of *O. abyssinica,* there was only slightly positive correlation between germination percentage and thousand-seed-weight.

The germination value was higher for seeds collected from Bullen. These seeds were relatively heavier in weight and hence germination values were positively correlated with seed weight. The timing of germination which in *C. majalis* was variable under field conditions was not related to seeds size (Eriksson, 1999). The lower number of days required for 50% germination and to accomplish germination in Bullen than Pawe might be due to environmentally induced dormancy (Bevington, 1986) at Pawe as it was in the lowest altitudinal range of the species.

Most results in this study are, of course, an outcome unlike that for other tree species. Bamboo has a tree-like function but it is a graminaceous species (Dwivedi, 1993; Yuming *et al*., 2004). Therefore, its seeds may have characteristics that resemble grass seeds, rather than seeds of trees species. Anantachote (1988) also pointed out that the flower and seed characteristics of bamboo are unique.

Conclusion

The study revealed that it is possible to harvest much seeds from gregarious flowering of *O. abyssinica*, despite the proportion of seed-bearing fruits per fruit aggregate and per collection height is smaller. The seeds were also found to have high germination percentage, germination speed and germination energy. The seedlings were also observed to have fast growing, which needs some adjustment in sowing to synchronize with the planting time. Since most of the seed quality measurements did not show statistically significant difference among the three fruiting portion of the culm, it is possible to harvest fruits at any height of the culm.

The variation in most seed parameters among the clumps on different land use type discerns the effect of environmental factors on the performance of *O. abyssinica* and which indicates the need of site selection. *O. abyssinica* produces a considerable amount of seed which can be used for mass seedling production. But the seed collection and processing is tedious and difficult which needs the development of some mechanisms that ease the collection and processing. The higher seed set on *O. abyssinica* clumps found on protected natural forest suggests the possibility of cross pollination and possibility of wind as a pollinator and the lower seed set on homestead and grazing lands, as the clumps were found apart to each other, pollination might have hindered. This also necessitates the determination of appropriate planting distance between the clumps for effective fertilization.

Most of the findings of this study work were compared with the findings of other species of plants as there was very limited research output conducted on *O. abyssinica* particularly with regard to seed and fruit characteristics. In the same study, it was also mentioned that reproductive allocation varies considerably between branches; second and more importantly, non-reproductive branches may constitute an important fraction of tree branches. But they are not found in *O. abyssinica*. This might be because of the nature of *O. abyssinica*. For example, Young & Augspurger (1991) categorized *O. abyssinica* as one of the semelparous plants, which is characterised by mass translocation of all resources to reproductive structures during the time of reproduction. Despite these facts, this difference was not reflected in *O. abyssinica* seeds and fruits. Moreover, there were no non-reproductive/vegetative branches during the gregarious flowering period of the species. Therefore, the points given in the recommendation part of this paper should be given due attention.

Recommendations

Awareness creation to the local community about the decimating effect of cutting *O. abyssinica* culms before fruits and seeds mature needs due attention. Preparation of on-shelf plans and projects such as seed collection and plantation establishment are of great concern to utilize the seed resource that is obtained during the gregarious flowering of *O. abyssinica*. The remaining natural stands of the species, which currently are not flowering need to be supervised every year for flower and seed setting and the available seeds should be collected and used for carrying out plantation activities in the region or other areas with similar agro-ecological zones, in which this plant can grow.

Since *O. abyssinica* seed is infrequently produced and has poor viability, and plantations are difficult to raise and protect on a large scale, areas where the species is potentially at risk should be among the highest priorities for action to secure the persistence of wild populations of *O. abyssinica* and improve the knowledge base for their conservation and management. As there is abundant seed near the flowered clump, sufficient regeneration most probably will spring up and seedling regeneration will come up in large numbers, several times more than the required for the stocking in the area, except in areas where the soil is too hard. Therefore, protection of flowering bamboo areas is of a paramount importance.

Since the embryo of *O. abyssinica* is very sensitive to damage during seed processing, great care should be taken in order not to damage this essential part of the seed. The susceptibility of *O. abyssinica* seeds to damping-off fungus during germination is very critical and hence aeration and watering frequency should be given due attention during seed germination either in field or laboratory. Plans should be devised on how to use or sale the drying culms of the species during the flowering stages of the plant. This could be a source of income that can be utilized in *O. abyssinica* development activities such as area closure, seedling production and plantation establishment. In order to obtain a complete picture of the whole process understanding the patterns of reproductive allocation at each hierarchical level is important. Research in collection, storage and increasing the longevity of *O. abyssinica* seeds is of a paramount importance in order to utilize the resource wherever available. Research with regard to natural regeneration and understanding of the nature of growth as well as life cycle should be started in the near future.

Acknowledgements

We are grateful to the Swedish International Development Cooperation Agency (SIDA) for the provision of funds for this research work. We also acknowledge the valuable comments of Dr. Mulugeta Lemenih for his valuable comments during the first initiation of the research proposal and Dr Jeremy Flower Ellis for editing the manuscript. We are also grateful to Pawe Agricultural Research Centre for providing office, laboratory, lodging and transportation facilities during the study time. We would like to thank the staff of Metekel Zone Department of Agriculture for the provision of secondary information about the study area.

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