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Study on Fruit Production and Fruit Characteristics of *Oxytenanthera abyssinica* (A. Richard Munro) in Benishangul Gumuz Regional State, Northwestern Ethiopia

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Abstract

O. abyssinica is a multipurpose plant that can contribute to the economic development of a nation. To investigate the fruit production and fruit characteristics of the species a study was conducted in Pawe and Bullen districts of Benishangul Gumuz Regional State, Ethiopia. The bamboo growing areas were stratified in to four classes based on disturbance levels. In each class, 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 and the aggregate fruits were harvested. Two sites and three fruit-collection heights (top, middle and bottom) were treated as factors. Number of fruits per aggregate fruit, number of seed bearing fruits per aggregate fruit and their percentages, and number of fruits per collection height were determined.The study revealed that the studied parameters did not show statistically significant difference among fruit collection heights on the culm as well as on fruit collection sites and fruit collection height interaction effects (α=0.05). It was also found out that O. abyssinica has low number of seed-bearing fruits. It is possible to collect fruits on the culm, regardless of sites and fruit collection heights as most of fruit characteristics were found almost the same along the different fruiting portion of the culm. Flowering of O. abyssinica is a critical stage and hence appropriate management and development interventions need to be considered whenever the species is flowering and setting seed.

Keywords: *Fruit characteristics; fruit production; Oxytenanthera abyssinica*

Introduction

Among the various bamboo species, which exist in the world, there are two species of bamboo in Ethiopia: the highland bamboo, *Yushinia alpina*, and the lowland bamboo, *O. abyssinica*. *O. abyssinica* is prominent in river valleys and locally on the escarpment of western part of the country. One of these areas harboring this species is Benishangul Gumuz Regional State of Ethiopia (Ensermu *et al*., 2000). The species co-exists with several other plants especially the *Combretum-Terminalia* broadleaved deciduous woodland vegetation which is common to this part of the country (Sebsebe *et al.*, 2003).

Bamboo has a considerable potential for socio-economic development (Baghel *et al*., 1998; Kumar *et al*., 1998; Perez *et al*., 1998; Sharma *et al*., 1998; Kumar &Sastry, 1999) and for environmental protection (Kumar & Sastry, 1999; Bystriakova *et al*., 2004). It can be used for house construction, animal feed, human food, as an agroforestry species (Maoyi, 1994; Christanty *et al*, 1997), for maintaining soil fertility (Lakshmana, 1994; Christanty *et al*., 1996; Mailly *et al*., 1997), as source of cash income and as medicine for treating many types of diseases (Pol, 2002; Yuming *et al*., 2004). Bamboo forest is also a material source for furniture, building, pulp, particleboard, bioenergy, food, forage and medicine (Embaye, 2000). But in Ethiopia, the species is not exploited to its full potential. Its current use is mainly restricted to household level; primarily for housing, fencing and household amenities. The resource is also poorly managed and exploited, where harvesting from natural stands is unregulated and resulting in a serious depletion of the resource in the growing areas (Ensermu *et al*., 2000).

In the study area, particularly in Metekel Zone of the Benishangul Gumuz Regional State, most of the natural *O. abyssinica* forest is disturbed and not in their natural condition (personal observation). Protection and development endeavors afforded to this species are almost negligible.

O. abyssica flowers at long time intervals (*ca.*30 years according to the information obtained from the elderly people living in the area). During the study period, the species was flowering gregariously. This stage is critical for the re-establishment of the species. The negative outcome of bamboo flowering is documented in many research findings. For example, John & Nadgauda (2002) stated that the death of bamboo forest after gregarious flowering resulted in much loss, and precipitated an ecological crisis. Unless and otherwise the species is replaced by natural regeneration or artificial propagation, the survival of the species will be in question (Embaye, 2000; Ensermu *et al*., 2000; Kassahun, 2003). However, because of human interference, natural regeneration is becoming difficult (Kassahun, 2003) as closing the entire area is difficult because of increasing human population pressure and a corresponding increase in land demand. The same situation is well documented by Banik (1994).

Although *O. abyssinica* propagates both sexually and asexually from seed and rhizomes respectively (Azene *et al.*, 1993; Dwivedi, 1993; Kassahun *et al*., 2003), offsetting method of propagation for the species is difficult and cumbersome for large-scale plantations. Extracting and transporting rhizomes to longer distance plantations is a challenge in the use of this method (Kassahun, 2003). Moreover, Saharia & Sen (1990) stated that determining the age and origin of rhizome couldn't be ascertained in the case of large-scale collection, which might affect the future of the culm as the bamboo plantation established by this method may be disastrous. If the age of the parent plant is not taken into consideration, the new stand follows the age of the original planting materials and will flower within shorter time than the usual flowering cycle of the species. This may also be accompanied by the death of the culm if appropriate protection measures are not taken (Purohit *et al*., 1998) also indicated that only limited plantation objectives could be achieved by vegetative propagation. Hence, if seed is available, propagation by seed should be given priority wherever that is possible (Kassahun, 2003; Demelash *et al*., 2012). Therefore, after assessing the requirements, the encouragement of artificial regeneration of the species by collecting as much seed as possible is imperative (Dwivedi, 1993) as they are very convenient for propagation. Their small size and lightness make them more transportable for plantation establishment (Rao, 1994; Gera *et al*., 1998). Bamboo seeds are also potential part for tissue culture development (Williams, 1994) and are advantageous in regeneration as they are hardier in stressful environmental conditions (Samora, 1994). But little is known about the seed and fruit characteristics of the species.

To achieve rapid sustainable production of *O. abyssinica*, there is a need to understand the basic silvicultural requirements of the species among which fruit and seed characteristics is one important element. Considering the long flowering and seeding cycle of bamboos, the seeds are very valuable, and any loss due to various factors is of great concern (Mohanan, 1997); hence, investigation of the nature of the seeds of the species is important (Anantachote, 1988; Demelash *et al*., 2012). The seed production potential of the species cannot be known without studying the fruits.

Mature fruits do not invariably indicate mature seeds (Demelash *et al*., 2012), and in a few species fruits are set and mature without fertilization and seed development (FAO, 1985; Demelash *et al*., 2012). The case of *O. abyssinica* may not be a different situation as it is flowering gregariously which most probably need much energy and resource allocation. The number of fruits for *O. abyssinica* may not necessarily indicate the seed-production potential of the species. Therefore, quantification of the amount of viable seeds produced in the culm and fruit aggregates is necessary for seed collection.

The nature of the area where the species is growing may also have impact on the seed and fruit production of the species. This is evidenced by the nature of *O. abyssinica* plants growing on different site qualities. During the study it was observed that height and amount of fruit production differ among different land classes that are described above. Therefore, selection of the best provenance of desired species for a given site or region is necessary to achieve maximum productivity in plantation forestry (Negash *et al*., 2006).

This study was conducted with the general objective of generating information on the fruits of *O. abyssinica*. The specific objectives of the study were (1) to determine the fruit production potential and determination of the proportion of seed bearing fruits from the total harvest fruits. 2) to find out the effect of site and fruit collection heights of the culm on fruit production and other fruit parameters (3) to determine better fruit collection site and collection height for the plantation establishment of the species.

Materials and Methods

Description of the study Area

Fruits used for the study were collected from a population of *O. abysinica* in Bullen and Pawe special districts of Benishangul Gumuz Regional State, North Western Ethiopia (Fig. 1).The mean annual temperature at the seed collection districts are 1555.1mm (Pawe Meteorological station) and 1979.5mm (Metekel Zone department of agriculture) for Pawe and Bullen respectively. Pawe lies between $36^0$20' to $36^0$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 topography of Pawe special district is 4% mountain, 22% undulating, and 74% plain and that of Bullen district is 5%, 35% and 60%, mountain, undulating and plain respectively (Metekel Zone Department of Agriculture, personal communication).

Pawe special district has an altitude of 980–1050 m above sea level. 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) agro-ecological zones. The major soil groups are generally identified as Nitosols, Vertisols and fluvisols. The plains to gently undulating slopes have predominantly deep Vertisols and Nitosols (UNDP/ECA, 1998).

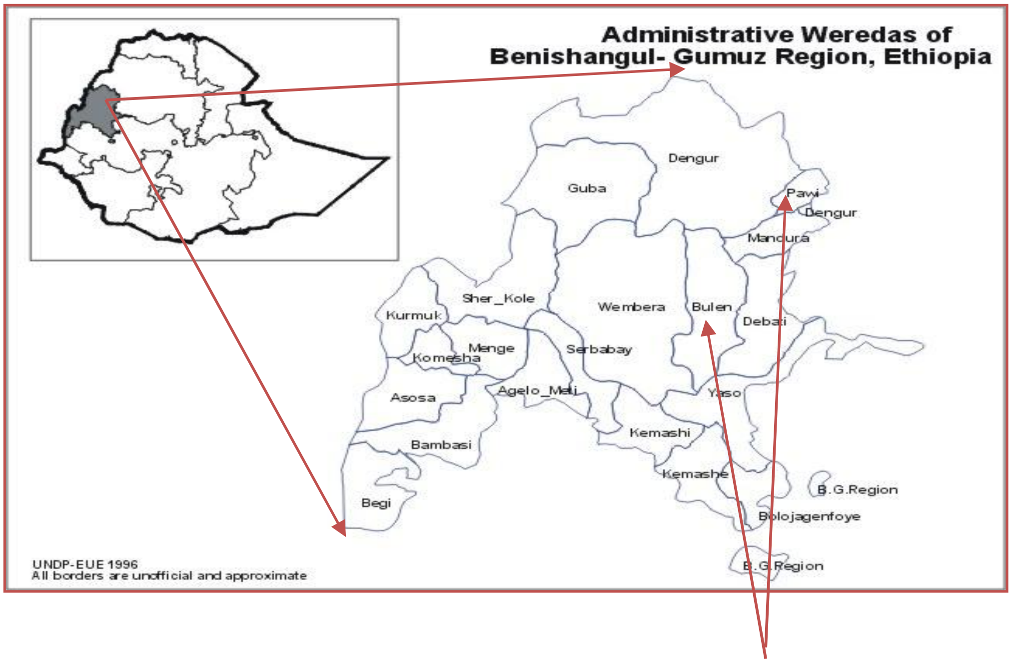

Fig1: Location of the study Area

Sampling Technique

A reconnaissance survey was carried out to find areas with flowering of *O. abyssinica* for fruit collection. Pawe and Bullen districts were selected purposively as they have fruiting *O. abyssinica*. The *O. abyssinica* growing areas were stratified in to protected area, free access natural forest, grazing land and homesteads based on their location and level of disturbance. From each strata, one central or nearest to central clump was selected for fruit collection. Three central culms from each sample clump were selected and their fruiting portion was divided into three equal parts: bottom, middle, and top. The fruits of each portion were totally harvested and placed in sacks, which were loosely tied and allowed to dry for a month in the open air under shade.

Ten aggregate fruits from each fruiting portion were selected randomly, separated in to single fruits. From these sample fruits the number of seed-bearing fruits was determined. Then dehulling (removing the outer coverings) of seeds was carried out manually to extract the seeds from. The harvested fruits from the three culms of a single clump were kept separately for consecutive sampling.

Experimental design

The experiment was considered as a split-plot design with randomized complete block design structure. The four strata (land use types) were used as blocks. The localities (Pawe and Bullen districts) were treated as the 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.

Method of data collection

Number of aggregate fruit per collection height: All the aggregate fruits of the three fruiting portions were collected and the number of aggregate fruits at each fruit-collection height of the culm was determined by counting.

Number of fruits per aggregate fruit: The aggregate fruits from each collection height were mixed thoroughly and ten aggregate fruits were selected randomly. These sample aggregate fruits were separated into single fruits and counted manually. Then mean number of fruits per aggregate fruit was determined.

Weight of one aggregate fruit: The fresh weight of ten randomly selected aggregate fruits from each collection height was weighed on a sensitive digital electronic balance (±0.1 g), as soon as they had been collected from the sample culms. The same aggregate fruits were also weighed after air-drying to determine the weight of one aggregate fruit on an air-dry basis. The mean weight of one aggregate fruit was then determined.

Number of seed-bearingfruits per aggregate fruit, collection height and culm: The number of seed-bearing fruits per aggregate fruit, collection height and culm was determined from ten randomly selected aggregate fruits for each fruit collection height and each site. These randomly selected aggregate fruits were separated into single fruits, and the seed-bearing fruits were selected manually. The separated seed-bearing fruits were also counted, to discover the proportion by number of seed-bearing fruits per aggregate fruit, and to extrapolate for collection height and culm.

Number of fruit and seed per culm, clump and collection height: The number of fruits collected at different heights of the sample culm at different collection sites was determined by collecting all aggregate fruits of *O. abyssinica*. To do so, the three sample culms were held down and the fruiting portion was measured with a tape and divided into three equal parts. All aggregate fruits were collected and counted. The number of aggregate fruits and their weight at different levels on the culm were averaged over the three culms of the same sample clump to obtain the corresponding value per collection heights. The number of fruit in the culms was determined by adding the values of the three collection heights of the same culm. The number of fruits per clump was also determined from the number of culms in the clump.

Data Analysis

Both descriptive and inferential statistics were used. 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. The least significance difference (LSD), included in the SAS statistical package, and was used.

Results

Observable Seed and Fruit Characteristics

When *O. abyssinica* flowers, every leafy branch develops in to a flowering shoot and leaves turn to brown and gradually drop off. Each branch develops the flowering units (pseudo spikelets or spikelets) at its nodes and apices, and flowering side branches develop from its basal parts. A flowering culm has all of its originally leafy branches transformed into flowering shoots and buds at culm and branch nodes can also develop directly into pseudo spikelet clusters. The culms in the clump are somewhat arching outwards and found to vary among clumps (Fig.2: A, B & C).

Fig 2: Fruiting and branching of *O. abyssinica*

Although the arrangement of the fruits on the aggregate fruit varied, mostly they were arranged in a circular manner. The fruits are arranged into aggregate fruits that are composed of spikelets/single fruits. Aggregate fruits attached to the primary branches were larger than those attached to secondary and tertiary branches. The concentration of aggregate fruits also varied along the length of the fruiting portion of the culm.

Number of Aggregate Fruits per Collection Height

There was no statistical significant difference (α=0.05) in the number of aggregate fruits per collection height with location (P>0.1104) and fruit collection heights (P>0.3159) or their interactions (P>0.0932).Statistical significant difference was observed only between landuse types (P=0.0256). The maximum number of aggregate fruits recorded (119.8) was observed from the middle fruiting portion of the culm at Pawe site while the minimum value (62.3) was recorded from the bottom portion of the culm.

Weight of one Aggregate Fruit

There was no statistically significant difference between the study sites (p > 0.2052; 6.59 g and 6.71g respectively for Pawe and Bullen) and among collection heights (p>0.504; 6.79 g, 6.58 g and 6.57 g for top, middle and bottom), but there was highly statistical significant differences (p <0.0001) among the different land use types in weight of one aggregate fruit. When the mean values were compared at Pawe, top, middle and bottom fruiting portions of the culm showed 6.60, 6.67 and 6.51 g per aggregate fruit. At Bullen, the maximum weight of one aggregate fruit (6.64 g) was recorded in the bottom fruiting portion of the culm followed by the middle (6.50g) and the top (6.14 g). The average weight of one aggregate fruit at Pawe and Bullen was 6.59g and 6.71 g respectively. When the data were averaged across the two locations, the highest value (6.79 g) was recorded at the top fruiting portion of the culm. The middle and bottom fruiting portions of the culm showed almost similar weight (6.58 & 6.57 g respectively). In general, the overall average weight of one aggregate fruit was found to be 6.80g (Table 2).

Number of Fruits per Aggregate Fruit
The number of fruits per aggregate fruit differed significantly between the seed collection sites (p=0.0266) and among the different land use types (p<0.0001) but there was no difference among the collection heights (p>0.299) nor for the interaction between study site and collection height (p >0.1861) (Table 1). The highest value (89.25) was recorded at Pawe from the top fruiting portion of the culm; while the lowest number (71.25) was recorded from the bottom fruiting portion of the culm at Bullen (Table 2). When collection height is considered across the study sites, the average number of fruits per aggregate fruit was higher in the middle (86.75) followed by top and bottom fruiting portion of the culm.

Number of Seed-bearing Fruits per Aggregate Fruit
There was a highly significant difference between the study sites (p<0.0001) and among the different landuse types (p<0.0001) in the percentage of seed-bearing fruits per aggregate fruit, but there was no difference among the collection heights (p>0.0895), nor the interaction of the study sites and the collection height (p>0.2066). Numerically the highest value (16.25) was recorded at Bullen from the middle fruiting portion of the culm; while the lowest number (7.33) was recorded from the top fruiting portion of the culm at Bullen site (Table 2). When the study sites are considered alone, Bullen district had the highest value (14.33) while Pawe had a value of 8.92.

Percent of Seed-bearing Fruits per Aggregate Fruit
There was significant difference between the study sites (p=0.0348), land use types (p=0.0012) in the percentage of seed-bearing fruits per aggregate fruit; however, there was no significant difference among the fruit collection heights of the culm (p>0.2156) and location with collection height interactions (p>0.1773). When only collection height was considered, the highest percentage of seed-bearing fruits per aggregate fruit (15.37) was recorded from the middle collection height and the lowest (13.45) was recorded from the top collection height. Across the sites, the mean percentage of seed-bearing fruits per aggregate fruit was 14.31. In general, a higher percentage of seed-bearing fruits per aggregate fruit were recorded from the Bullen site (Table 2).

Number of Fruit and Seed-bearing Fruits per Collection Height
There was statistically significant difference between the study sites (p=0.0373; 1225 *vs*902 for Bullen and Pawe respectively) in the average number of fruits per collection height. This variable also showed highly statistical significant difference among land use types (p=0.009). Neither fruit collection heights nor the interaction of location with fruit collection sites showed statistical significance difference in the number of fruits per collection height (Table 1; Table 2).

Among the collection heights, the highest number of seed bearing fruits (1316) was recorded in the middle followed by top (967) and bottom (906) fruiting portions of the culm. It was also found out that, on average, about 1063 seed-bearing fruits can be collected per collection heights. When location and collection heights were combined, the maximum number of seed-bearing fruits was recorded in Bullen district, in the middle portion of the culm, where it was *ca.* 1643. The minimum value (690) was recorded in Pawe, in the top fruiting portion of the culm.

With regard to the number of seed bearing fruits per collection height there was no statistically significant difference due to the variations considered except that of the source landuse types, which showed highly statistical significant difference (p<0.0001).

Percentage of Seed-bearing Fruits per Collection Height
The percentage of seed-bearing fruits in each location and collection height was statistically non-significant because of the source of variations considered at (Table 1). There was a slight numerical difference among the fruit-collection heights of the culm, and between locations, whereby the highest value was found at Bullen in the top fruiting portion of the culm. The average percentage of seed-bearing fruits per collection height at Pawe and Bullen was 11.74 and 16.88 respectively. With regard to collection height, the top, middle and bottom fruiting portion of the culm showed 13.45, 14.0 and 15.37% of seed-bearing fruits respectively.

Table 1: ANOVA for the studied parameters on *O. abyssinica* fruits and seeds

	Mean squares				
Variables	Land use	Loc	Cht	Loc*Cht	Error
DF	3	1	2	2	12
NOFAG	10.138*	6.784 NS	2.9 NS	6.645 NS	2.283
WOOFA	38.759**	1.054 NS	0.43 NS	0.19 NS	0.59
NFPFAG	6.3115**	0.9801*	0.2931 NS	0.4513 S	0.2401
PSPFAG	197.517**	107.104*	33.09 NS	37.92 NS	18.91
NSBFPFAG	5.038**	2.344**	0.174 NS	0.1054 NS	0.058
NFPCHT	1535.22*	1372.14*	378 NS	680.31 NS	250.37
NSBFPCHT	564.94**	42.14 NS	68.74 NS	56.37 NS	33.07
WOOFAD	11.155**	4.27**	0.44 NS	0.43 NS	0.26
NOFPKGDR	200866219.6**	184437792.7**	1701489.0 NS	177064.3 NS	3958203

**, ** 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, NOFAG=number of aggregate fruits, WOOFA=weight of one aggregate fruit, NFPFAG=number of fruits per aggregate fruit, NSBFPFAG=number of seed-bearing fruits per aggregate fruit, PSPFAG=percentage of seed-bearing fruits per aggregate fruit, NFPCHT=number of fruits per collection height, NSBFPCHT=number of seed-bearing fruits per collection height, WOOFAD= air-dry weight of one aggregate fruit and NOFPKGDR = number of air-dryfruits per kg.*

Discussion

Most of fruit characteristics of *O. abyssinica* showed statistical significant difference among study sites. However, none of the parameters considered showed statistical significance difference among the collection heights. The absence of statistically significant difference on the weight of single aggregate fruits along the fruiting portion of the culm may be due to lack of differential resource allocation. This is supported by the nature of the species. *O. abyssinica* flowers gregariously and every bud sets flowers and fruits at the same time. This is the unique nature of the species, hence all resources may have been allocated to the reproductive phase only, which is the characteristic of semelparous plants, which includes *O. abyssinica* (Young &Augspurger, 1991). Had there been vegetative branches, they would have shared the available resources, and some might have been disadvantaged (Obeso, 2004), which would have been reflected in variations in the weight of aggregate fruit on different fruiting portions of the culm. Research conducted on other species showed contrary results. This may in most cases attributed to the nature of the plant. For example, Ngulube*et al.* (1997), found out that there is variation on the amount of seed produced among plants of *Uapacakirkiana* species populations.

The difference between the study sites in the number of seed-bearing fruits per aggregate fruit ($p < 0.0001$) might have been due to environmental factors such as humidity, soil nutrients and fertility; biotic factors such as insects, pests and disease and animals (Gordon & Rowe, 1982; Albrecht, 1993; Marchelli1 & Gallo, 1999). The statistically significant difference in the number of seed-bearing fruits per aggregate among different disturbance regimes where the fruits were collected may be attributed to the variation in site quality. For instance, Bullen having 65% of sandy soils showed higher value than Pawe which has higher proportion of clay soil. *O. abyssinica* has better performance including seed setting on sandy soils rather than on clay (vertisols). Because gregarious flowering is characterized by flowering and seed setting in the whole clump at the same time, and flowers in the same year, the aggregate fruits at all collection heights consequently had a similar number of pure seeds, although the size of the whorls of fruit varied from site to site and from one landuse type to another (Holland *et al*., 2004).

The absence of statistically significance difference in the number of fruits and seed bearing fruits among different collection heights of the culm disagrees with many of the findings for other plant species. This may be again because of the nature and architecture of the plants of the species. Fore example, the study conducted on *Iris fulva* by Wesselingh & Arnold (2003), showed that the first apical flower had the highest fruit-set and seed production and decreased towards the base of inflorescences, while later opening flowers showed higher fruit-set. But a study conducted by Wesselingh & Arnold (2003) shows that overall fruit-set (total number of fruits per stalk divided by the number of flowers) does not differ significantly among level classes of inflorescence, and overall seed-set (total number of seeds divided by the number of flowers), does not differ significantly among level classes. The absence of statistically significant difference in the amount of fruits and seed-bearing fruits among the various fruiting portions of the culm may have several causes. One observable reason may be the architecture of the plant itself. The middle fruiting portion of the culm showed relatively longer sub-branches and medium internode length, hence a higher number of nodes than the bottom, and a smaller number of nodes but longer sub-branches than the top. Although the length of internodes decreases upwards, the number of nodes (branches for fruit-set) increases (Seethalakshmi & Kumar, 1998). Therefore, the effect of these factors might finally have cancelled each other out, and resulted in a rather similar number of fruits, aggregate fruits and seeds at each fruit-collection height of the culm.

Table 2: Mean (±S.E) values of different parameters taken on *O. abyssinica* and fruits

Source of variation		NOFAG	WOOFAG	NFPFAG	NSBFPFAG	PSBFPFAG	NFPCHT	NSBFPCHT	WOOFAD	NOFPKGDR
Land use	Protected Natural forest	82.33±6.91A	8.6±0.79A	90.7±6.96A	21.8±4.7A	23.1±2.99A	7482±1017.7B	1783±424A	6.0±0.9A	16069±1425C
Mean± S.E.	Homestead	81±12.89A	4.1±0.34B	57.7±5.4B	6.5±1.12C	12.68±1.69B	4781.3±1031.87B	528±139B	2.9±0.19C	20047±1337B
	Grazing land	83.3±22.87A	5.2±0.16B	97.2±5.02A	7.7±1.43C	8.37±1.85C	8442.2±2594.7AB	535±95B	3.4±0.3C	29746±3727A
	Natural forest but accessed	132.8±13.2B	8.5±0.7A	89.5±13.3A	10.5±0.7B	13.1±2.39B	11651.3±1592.1A	1405±215A	4.3±0.46B	20565±1271B
	LSD (5%)	37.93	0.96	10.58	2.19	2.18	3694.7	606.25	0.64	2502.7
Location	Pawe	103.8±10.3A	6.6±0.56A	88.1±8.31A	8.9±0.92B	11.4±1.175B	9558.9±1532.4A	902±103A	3.7±0.31B	24379±2492A
	Bullen	85.9±13.2A	6.7±0.86A	79.4±5.81B	14.3±3.1A	16.9±2.6A	6619.5±968.97B	1225±311A	4.6±0.6A	18835±1161B
	LSD (5%)	26.82	0.68	7.48	1.55	1.53	2612.6	428.68	0.46	1769.7
Collection Height	Top	89.9±16.03A	6.8±0.95A	84.5±9.27A	10.5±2.9A	13.45±3.17B	7255.2±1174.95A	906±243A	4.1±0.6A	22117±2843A
	Middle	107.1±12.4A	6.6±0.93A	86.7±9.21A	12.4±3.6A	14.1±2.95AB	9452±1666.04A	1316±394A	4.4±0.7A	21220±2743A
	Bottom	87.6±15.88A	6.6±0.82A	80±8.75A	12±2.49A	15.37±2.64A	7560.4±2028.19A	967±193A	4.0±0.6A	21483±2333A
	LSD (5%)	32.85	0.83	9.16	1.90	1.87	3199.7	525.03	0.56	2167.4
Location and Collection Height interaction	Pawe-Top	78.7±11.34A	6.6±1.31A	89.2±17.6A	8.3±1.84A	11.17±3.48A	7172.25±2040.5A	690±202A	3.7±0.7A	24908±5063A
	Pawe-Middle	119.7±11.8A	6.7±0.81A	86.7±16.3A	8.5±1.55A	11.67±3.49A	10725±2714.5A	989±162A	3.7±0.4A	23835.25±5161.28A
	Pawe-Bottom	113±23.98A	6.51±1.0A	88.2±13.6A	10±1.68A	12.37±3.04A	10779±3384A	1026±167A	3.7±0.6A	24394±3983A
	Bullen-Top	115.7±39.3A	6.14±1.1A	73±8A	7.3±2.73A	11.35±4.87A	7882±1989.21A	947±590A	3.4±0.0A	21320±2414A
	Bullen-Middle	94.5±21.64A	6.5±1.85A	86.7±11.4A	16.2±6.8A	16.52±4.96A	8179±2122.32A	1643±792A	5.1±1.4A	18606±1981A
	Bulen-Bottom	62.2±13.12A	6.6±1.45A	71.7±11.2A	14±4.83A	18.38±4.17A	4341.3±914.6A	908±377A	4.2±1.1A	18573±1976A
G. MEAN± S.E.		94.88±8.39	6.8±0.50	83.7±5.04	11.63±1.67	14.31±1.62	8089±938.05	1063±164	4.15±0.35	21607±1464

Mean values with the same letter in the same column and the same source of variation are not significantly different α = 0.05. NOFAG = number of aggregate fruits, WOOFAG = weight of one aggregate fruit (g), NFPFAG=number of fruits per aggregate fruit, NSBFPFAG =number of seed-bearing fruits per aggregate fruit, PSBFPFAG = percentage of seed-bearing fruits per fruits of one aggregate fruit, NFPCHT=number of fruits with impurities per collection height, NSBFPCHT=number of seed-bearing fruits per collection height,WOOFAD= air-dry weight of one aggregate fruit and NOFPKGDR = number of air-dryfruits per kg..G. MEAN = Grand mean, S.E= Standard error of the mean.

Another reason for the absence of differences in seed-bearing fruits in different fruiting portions of the culm, may be similarity in the timing of flowering, since *O. abyssinica* is a fast- growing plant, and accomplishes its growth within a short period. Had there been differential flowering along the length of the culm, the results of Halbrecq *et al*. (2005), which stated that flowers which bloom earlier in the spike, tend to have a higher probability of seed-set than those that bloom later on the same spike, would also have been true for *O. abyssinica*. The current result is contrary to many research findings conducted on other plant species. For example, Halbrecq *et al*. (2005) also found that spikes of *Fagopyrum esculentum* Moench situated on the upper third of plants produce more flowers, and have a lower early abortion, which consequently results in better seed-setting than that of the spikes at the base of the main stem; young leaves in the upper part of the plant receive more light, and are photosynthetically more active. However, as was observed during the fieldwork, the gregariously flowering *O. abyssinica* at both study sites shed all their leaves. Also, the light (after shedding leaf) and spreading nature of *O. abyssinica* branches may also have allowed fruiting branches of the culm to receive more or less uniform light. *O. abyssinica* culms are arching slightly outwards from the clump (Fig. 2). This is a characteristic of some bamboo species, even some have pronounced arching so a clump that is well developed assumes a kind of "mushroom" shape (Wong, 2004).

Flowering order is frequently mentioned in literatures as having an impact on differential seed-setting in plants. For example Emms (1996) states that 'the first internal cause of differential fruit and seed set is resource competition among flowers therefore both the order of the anthesis and the position on the inflorescence can convey advantages to certain flowers. Flowers that open early in the flowering sequence can sequester resources before later flowers develop'. In contrast to this, a study conducted on *Iris fulva* (Iridaceae) by Wesselingh & Arnold (2003) shows that flowering order is not perfectly correlated with flower position. Therefore, the research results in this regard are not consistent.

Resource competition is also an important factor that can influence the amount of fruit and seed production in plants. For example, Wesselingh & Arnold (2003) found that fruit-set is highest at the apex of the inflorescences and decreases towards the base because of the top-down hierarchy in resource utilization, not because of flowering order. In contrast to this, a study conducted by Brunet (1996) states that there is basipetal development of inflorescences in *Aquilegia caerulea*, which coincides with flowering order (the first flowers having the highest fruit-set). The fact that not all flowers set fruit in *Iris fulva* may well be explained by resource limitation at the inflorescence level.

As there was an increase in fruit-set in the basal flowers by removing the topmost flowers, Wesselingh & Arnold (2003) postulated the existence of strong resource sink in the upper portion of the inflorescence and the gradient of hormones as the main reason for higher fruit-set. This supports the fact that the basal flower rarely sets fruit despite being closer to resources. The most likely physiological explanation, however, is that the apex produces hormones that will support fruit development further down the flowering stem, mechanism comparable to apical dominance (Cline, 1994).

But in the same study (Wesselingh& Arnold, 2003), it was found out that statements on pollen limitation and resource limitation of fruit- and seed-production should not be made without explicit reference to the level; plant, inflorescence, or individual flower as there are variations among flowers within an inflorescence, due to differences imposed by inflorescence design, such as in the amount of vascular tissue. This would cause certain flowers to have inherently low fruit- or seed-set, even if the amount of resources available were not limiting for the maximal fruit- or seed-set at the inflorescence level.

Conclusion

The proportion of seed-bearing fruits per fruit aggregate and per collection height of *O. abyssinica* is smaller. The variation in most fruit parameters among the clumps on different land use type discerns the effect of environmental factors on the performance of *O. abyssinica.* This indicates the need for the site selection in the development of the species.

The underlying cause for low number of seed-bearing fruits and lack of difference in most fruit characteristics of *O. abyssinica* among position of fruit on the culm is uncovered. Resource allocation to different part of a plant is a controversial issue and research outputs are not consistent to be used as a premise for fruit set along the fruiting portion of the culm. For example, Obeso (2004) states that investment in reproduction is a hierarchical process and it can be top-down or bottom-up depending on the species. 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 characterized 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* 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

Gregarious flowering in *O. abyssinica* is the critical time and management options are of a paramount importance and have tremendous impact on the continuity of this species. Among the various management options rescheduling felling operations, protection of natural regeneration, creation of rhizome bank and artificial regeneration are of the most important management considerations.Therefore, these management options should be practiced in the study area.

Protection of regeneration of *O. abyssinica* in flowered areas is also the most important operation because it will decide whether the species will again appear in the area. To scrutinize the naturally occurring patterns of flowering, fruit and seed production in *O. abyssinica*, and to know the factors that limit seed production / pollen, pollinator or resource availability or both/ and other factors for the cause of low seed to fruit ratio, follow-up and recording natural fruit and seed set and stigmatic pollen loads are of a paramount importance.
Studying and documenting the flowering cycle or the lifetime of *O. abyssinica* based on flowering and seed setting should also be one of the research agenda in the future.

- At the whole culm level, whether reproductive (especially for seed and fruit set) allocation depends on plant culm size or not.
- At the branch level, whether reproduction investment is evenly distributed or not between branches.
- At individual fruit and aggregate fruit level, the amount and cause of flower abortion if any and underlying cause of low seed set and the way in which resources are allocated within fruit? Are resources homogeneously or heterogeneously distributed between the seeds within the same aggregate fruit?
- Further research to investigate the real cause of low number of seed-bearing fruits per fruit at the aggregate fruit, branch and culm level will also be useful.

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