Octa Journal of Environmental Research **Jan. – Mar., 2015**
International Peer-Reviewed Journal ISSN 2321 3655
Oct. Jour. Env. Res. Vol. 3(1): 100-111
Available online http://www.sciencebeingjournal.com

Research Article

Octa Journal of Environmental Research
(Oct. Jour. Env. Res.) ISSN: 2321-3655
Journal Homepage: http://www.sciencebeingjournal.com

GUM ARABIC PRODUCTION POTENTIAL OF NATURALLY GROWING ACACIA SENEGAL VARIETIES IN KENYAN DRYLANDS

C Wekesa[a]*, BN Chikamai[b], GM Muturi[c], JK Lelon[c], MO Muga[c] and AM Luvanda[d]

a. Kenya Forestry Research Institute, Coast Eco-Region Research Programme-Gede, PO. Box 1078-80200, Malindi

b. Kenya Forestry Research Institute, National Forest Products Research Centre-Karura, PO. Box 64636-00620, Nairobi

c. Kenya Forestry Research Institute, Muguga Regional Research Center, P.O. Box 20412-00200, Nairobi

d. Kenya Forestry Research Institute, Dryland Eco-Region Research Programme-Kitui, PO. Box 892-90200, Kitui

*Corresponding author's Email: **chemukukefri@gmail.com**

Received: 25th March 2015 **Revised**: 28th March 2015 **Accepted**: 31st March 2015

Abstract: This study was undertaken between 2008 and 2010 to assess annual gum production potential per tree for different varieties of *Acacia senegal* (var. *kerensis*; var. *senegal* and var. *leiorhachis*) growing naturally in Kenyan drylands. Eight sample plots of 1.0 hectare were established, one at each site. All trees in each sample plot were measured for basal diameter and classified into three diameter size classes (3.0-6.0 cm, 6.1-9.0 cm and > 9.0 cm). Ten trees from each diameter class were selected for tapping while another ten trees left untapped as control. Results indicate that gum yield by different varieties of *A. senegal* varied with basal diameter (BD) size classes. *A. senegal* var. *senegal* yielded high quantities of gum compared to the other two varieties. Tapping increased yield by 47.1%, 91.8% and 85.7% for trees in diameter classes 3.0-6.0cm, 6.1-9.0cm and >9.0 cm respectively. On average, tapping increased gum production by 74.9%. These results can be used for estimating gum yield potential of naturally growing *A. senegal* in relation to the variety, tree size and site conditions. Besides, the upshot of these findings offers new management guidelines that can improve gum production through tapping for the economic, social and environmental benefits of local communities living in the drylands of Kenya.

Keywords: *Acacia senegal* varieties; Basal diameter; Gum arabic yield; Natural stands.

Postal Address: Chemuku Wekesa. Kenya Forestry Research Institute, (KEFRI), Coast Eco-Region Research Programme, P.O. Box 1078-80200, Malindi

INTRODUCTION

Acacia senegal is a legume and deciduous shrub or shrub tree belonging to the sub-genus, *Aculeiferum* (Arce and Blanks, 2001). The species grows to 2-15 m tall with a flat or rounded crown (Maundu *et al.,* 1999). It is highly branched with many upright twigs (Von Maydell, 1990). This species is a multipurpose African tree highly valued for centuries for gum arabic production, which is used in food, pharmaceutical and other industries (Anderson and Weiping 1992; ICRAF, 1992). It also plays a secondary role in agricultural systems restoring soil fertility and providing fuel wood as well as fodder to livestock (Obua *et al.,* 2006; Okunomo and Bosah, 2007). *A. senegal* is a xerophytic plant that grows in dry habitats that belongs to the family Mimosaceae. It is widely distributed because it tolerates aridity and eroded soils (Chiveu *et al.,* 2008). It is extensively spread in tropical and sub-tropical Africa, from South Africa northwards to Sudan (Raddad *et al.,* 2005). In Kenya, *A. senegal* is found growing in association with a wide range of vegetation types, from semi-desert grasslands to Anogeissus woodlands including dry Commiphora bushland. It prefers clay plains and rocky hill slopes such as Homa Hill, parts of Baringo, Turkana, Kajiado and Samburu Counties in Rift valley province, Isiolo and Mwingi Counties in Eastern province (Beentje, 1994; Chiveu *et al.,* 2008). Besides, high densities of pure stands of this species are found in many other parts of upper Eastern and Northern Kenya. According to Cheema and Qadir (1973), *A. senegal* tolerates a pH of 7.4 to 8.2. This species grows in an altitude ranging from 100 to 1700 m above sea level (Maundu *et al.,* 1999). It is generally recognized by its three-hooked prickles, central one curved downwards and the two laterals more or less curved upwards, or singly, the laterals being absent and with the flowers in spikes. In Kenya, *A. senegal* exhibits three different growth forms, recognized as varieties (Gachathi, 2002). The varietal differences in *A. senegal* are based on variation in natural distribution as well as differences in morphological characteristics such as presence or absence of hair on the axis of the flower spike, colour of the axis, shape of pod tips, number of pinnae pairs, occurrence of a distinct trunk and shape of the crown (Gachathi, 2002). The three different varieties of *A. senegal* found in Kenya are var. *senegal*, var. *kerensis*, and var. *leiorhachis* (Gachathi, 2002).

Generally, *A. senegal* var. *senegal* is recognized as a tree with a flat or rounded crown and rough non-papery and non-peeling bark commonly growing on sandy alluvial loamy soils in plains or at the foot of hills in semi-humid to semi-arid areas. *A. senegal* var. *kerensis* grows as a single or several-stemmed shrub with lateral branches forming near the base and with smooth yellowish-brown peeling bark on the stem. It is common on rocky hills and ridges or sandy plains in arid to very arid areas (Gachathi, 2002). *A. senegal* var. *leiorhachis* exhibits two growth forms; either as a struggling slender tree starting with a very branched bushy base then thinning out to 1-4 slender whippy erect tall stems with peeling bark or a well grown tree with open rounded spreading crown and yellowish papery and peeling bark on the main trunk. The whippy form occurs in clusters of small populations in extremely rocky gneiss-derived sandy soils in semi-arid to arid areas in plains while the tree form occurs in red deep sandy soils along drainage lines and areas with high water table (Gachathi, 2002). Gum arabic is defined as a dried exudate obtained from the stems and branches of *A. senegal* (L) Willd or *Acacia seyal* (FAO, 1999). Usually, gum arabic exudes from the cracks on bark of wild trees in the dry season, with little or none in the rainy season when the trees are in flowering phenological phase.

A preceding study conducted by Chretin *et al.,* (2008) indicates that gum arabic production in Kenya has been declining in recent years. Varying estimates of gum arabic yield have been presented (ITC 1972; FAO 1978; NAS, 1979; Duke, 1981; Muthana, 1988; Badi *et al.,* 1989; Ballal *et al.,* 2005; Dagnew, 2006; Chiveu *et al.,* 2009; Wekesa *et al.,* 2009). These estimates contain limited information on the yield of different varieties of *A. senegal* growing in regions with different ecological manifestation and hence hardly any reliable data are available to provide estimates of the potential production of the various varieties naturally growing in the gum belt particularly in Kenya. On average, a tree may produce 250 grams of gum arabic in two seasons (annually), although, production can range from a few grams to as high as 10 kg (NAS, 1979; Dagnew, 2006) or 0.2 to 6.7 kg (Duke, 1981). A yield of between 0.66 and 0.81g per tree in a season has been reported for *A. senegal* var. *kerensis* in Kenya (Chiveu *et al.,* 2009). The highest yield has been observed in individuals aged from 7 to 12 years (NAS, 1979; Duke, 1981). According to ITC (1983), yield per hectare per year ranges between 30 to 40 kg in case of open stands and as much as 100 Kg in case of dense stands. Yields from cultivated trees are said to increase up to the age of 15 years, when they level off and then begin to decline after 20 years (ITC, 1983; Abdel, 2001). Presently, the major problem facing gum arabic industry in Kenya is lack of reliable information on gum arabic yield that can be used as a basis for monitoring gum arabic production for the three different varieties of *A. senegal* growing in areas with varying ecological and environmental conditions. Consequently, there is need to evaluate quantitatively gum arabic yield by these varieties growing in Kenyan drylands and in sites with different ecological characteristics. Moreover, there is diminutive information on how tapping and tree size and/or age affect the quantity of gum arabic produced by *A. senegal* varieties growing naturally in the drylands of Kenya.

The aim of the current study was to determine and analyze the gum arabic yield variations in relation to different varieties of *A. senegal*, site ecological conditions, tapping and the size and/or age of the tree in order to provide definitive information on the yield potential of different varieties which is needed to improve gum arabic yields and offer management guidelines for enhancing gum production for the benefit of local communities living in the drylands of Kenya.

EXPERIMENTAL

Materials

This study was conducted between 2008 and 2010 in Isiolo, Baringo and Kajiado Counties of Kenya (Figure 1). The study sites were purposely selected because of the presence of high natural population of *A. senegal* varieties. Eight sites namely Ngare Ndare (var. *kerensis*), Kulamawe (var. *leiorhachis*), Ntumburi (var. *senegal*) and Daaba (var. *kerensis*) in Isiolo County, Kimalel (var. *kerensis*), Solit (var. *senegal*) and Rimoi (var. *senegal*) in Baringo County and one site (var. *senegal*) in Kajiado County were selected. Sampling plots measuring 100x100 m (1.0 Ha), one in each site were established (Table 1).

Table 1. Latitudes, longitudes and elevations data of the study sites

Site	*A.senegal* variety	County	Northings	Eastings	Altitude (m.a.s.l)
Ntumburi	Var. *senegal*	Isiolo	00°11'29. 9"	037°30'46. 7"	1725
Ngare Ndare	Var. *kerensis*	Isiolo	00°30'39. 1"	037°22'16. 1"	984
Daaba	Var. *kerensis*	Isiolo	00°32'00. 2"	037°45'39. 9"	935
Kulamawe	Var. *leiorhachis*	Isiolo	00°33'32. 8"	038°01'38. 6"	750
Kajiado	Var. *senegal*	Kajiado	01°53'08. 6"	036°45'25. 4"	1741
Rimoi	Var. *senegal*	Baringo	00°39'52. 5"	035°34'16. 4"	1152
Solit	Var. *senegal*	Baringo	00°25'38. 4"	035°55'06. 5"	1283
Kimalel	Var. *kerensis*	Baringo	00°27'00. 0"	035°52'00. 0"	1686

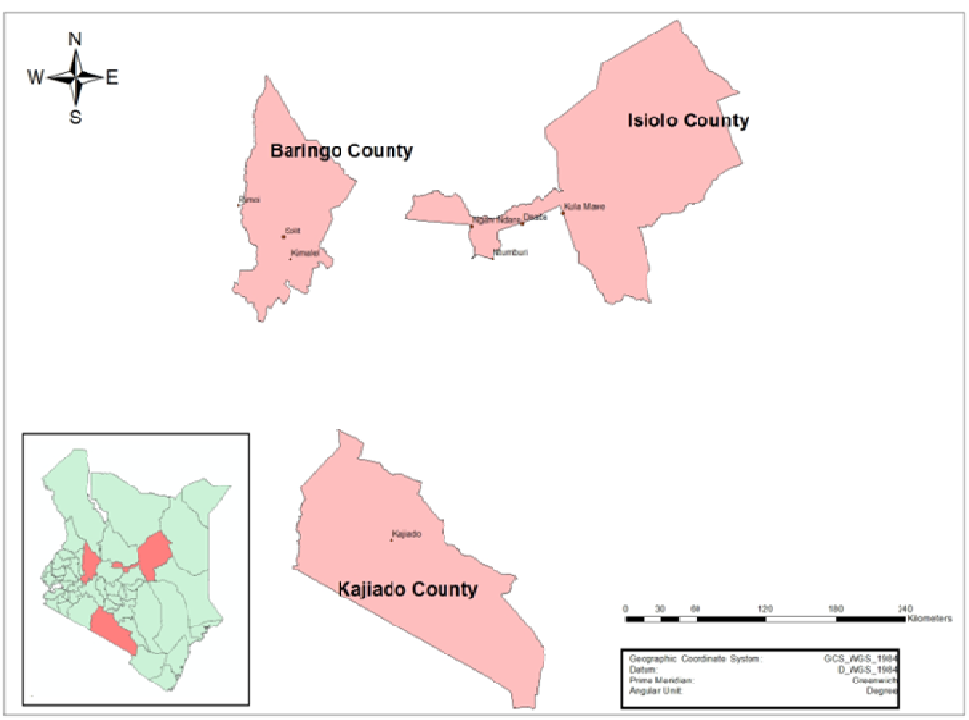

Figure 1. Map of Kenya showing Counties and the location of the study sites

All individual *A. senegal* trees within each plot were enumerated, assigned numerical numbers and their basal diameter (BD) measured. Trees were classified into three different diameter size classes as follows: 3.0-6.0 cm, 6.1-9.0 cm and >9.0 cm. An assumption was made that trees with basal diameter classes of 3.0-6.0 cm, 6.1-9.0 cm and >9.0 cm were aged 5-9, 10-14 and 15-20 years old respectively. Thus, ten trees were randomly selected from each diameter size class for tapping using Excel Stata computer Programme. A similar procedure was repeated to select an additional ten trees from each diameter size class that were left untapped as a control. A total of 480 trees representing both tapped and untapped trees in equal ratio for each of the three diameter size classes were sampled for gum arabic collection in the eight study sites. The selected trees for tapping were tapped either on the stems or branches depending on the diameter of the stem and the branches. Consequently, all branches with a diameter equal to or greater than that of arm's wrist (>3.0 cm) were tapped. On the other hand, those trees with branches with a diameter less than that of arm's wrist (<3.0 cm) were only tapped on the main stem. The tapping tool used was the Sonke, a standard tool that was developed in Kordofan, Sudan. The diameter of tapped branches for the selected *A. senegal* varieties was measured and recorded. Tapping was done three weeks after the end of long rain season when the trees had shed about 50% of the leaves. The incision had a length of 80 cm and a width of 2.5 cm. The first picking was done four weeks from the date of tapping and thereafter at a regular interval of two weeks until the end of dry season. The quantity of gum obtained from each tree was weighed and recorded to estimate the gum arabic production potential.

Statistical analyses

Given that not all sampled trees were able to produce gum during the assessment period, only data for the productive trees was analyzed. Data collected were analyzed for descriptive statistics for mean, minimum, maximum and range values of gum yield per individual tree in each diameter class and for each of the varieties in each study site. One-way ANOVA was performed with site, *A. senegal* variety and diameter size class as treatment factors. The Least Significance Difference (LSD) comparison method was used to test significant differences in gum arabic yield between sites, *A. senegal* varieties and diameter size classes where the F-test demonstrated the significance difference at 95% probability level. All the data collected were analyzed using Genstat version 10.0 statistical package.

RESULTS AND DISCUSSION

Trends in gum arabic yield

The yield trends of gum varied with varieties of *A. senegal* and site conditions and in particular edaphic characteristics (Figures 2 and 3). Gum yield of *A. senegal* var. *kerensis* in Daaba increased with increase in basal diameter for both tapped and untapped trees (Figure 2). However, *A. senegal* var. *kerensis* in Ngare Ndare showed a different pattern with tapped trees having a basal diameter of 6.1-9.0 cm producing more gum than tapped trees falling under diameter classes 3.0-6.0 cm and >9.0 cm. In Ngare Ndare, untapped trees in diameter class >9.0 cm yielded more gum than those found in diameter class 6.1-9.0 cm while untapped trees in diameter class 3.0-6.0 cm did not produce gum at all during the entire assessment period. Gum production by *A. senegal* var. *senegal* in Ntumburi was greatly dependent on the age/size of the tree (Figure 2). The quantity of gum produced decreased as the diameter of the trees increased in both tapped and untapped trees. Tapped *A. senegal* var. *leiorhachis* trees in Kulamawe produced gum in all the three diameter classes. Just like *A. senegal* var. *senegal* in Ntumburi, the yield of gum for tapped *A. senegal* var. *leiorhachis* trees with small girth was higher compared to trees with larger diameters. However, untapped trees of *A. senegal* var. *leiorhachis* in diameter classes 6.1-9.0 cm and >9.0 cm failed to produce gum during the entire production seasons studied. *A. senegal* var. *senegal* in Rimoi with basal diameter ranging from 6.1 to 9.0 cm produced the highest amount of gum when tapped followed by trees with a diameter of greater than 9.0 cm and then small sized trees with a diameter less than 6.0 cm (Figure 3). Correspondingly, yield of gum of untapped trees was high in diameter class 6.1-9.0 cm. This was followed by *A. senegal* var. *senegal* trees occurring in diameter classes 3.0-6.0 cm and >9.0 cm in that order. The gum yield trend in Rimoi was similar to what was observed in Ngare Ndare even though the varieties are different (Figures 2 and 3). In the case of Kimalel (*A. senegal* var. *kerensis*), the yield of gum showed a distinctive trend for both tapped and untapped trees (Figure 3). As the size (diameter) of the trees increased, the yield of gum declined. A similar trend was observed in Solit for tapped *A. senegal* var. *senegal* trees across all diameter classes, where gum yield decreased as diameter increased. However, non-tapped trees in Solit occurring in diameter classes 3.0-6.0 cm and 6.1-9.0 cm did not yield quantifiable gum and hence underscoring the importance of tapping as a management strategy to enhance productivity.

Both tapped and non-tapped *A. senegal* var. *senegal* trees in 3.0-6.0 cm diameter class in Kajiado were not productive; no single tree yielded measurable gum (Figure 3). Nevertheless, tapped trees with diameter classes of 6.1-9.0 cm and >9.0 cm produced considerable quantity of gum. Likewise, untapped trees with large diameter (>9.0 cm) produced little amount of gum.

Comparison of mean annual gum arabic production by the three *Acacia senegal* varieties

The mean values for gum yield for the three varieties were determined for the three-year period. The results are presented in Table 2.

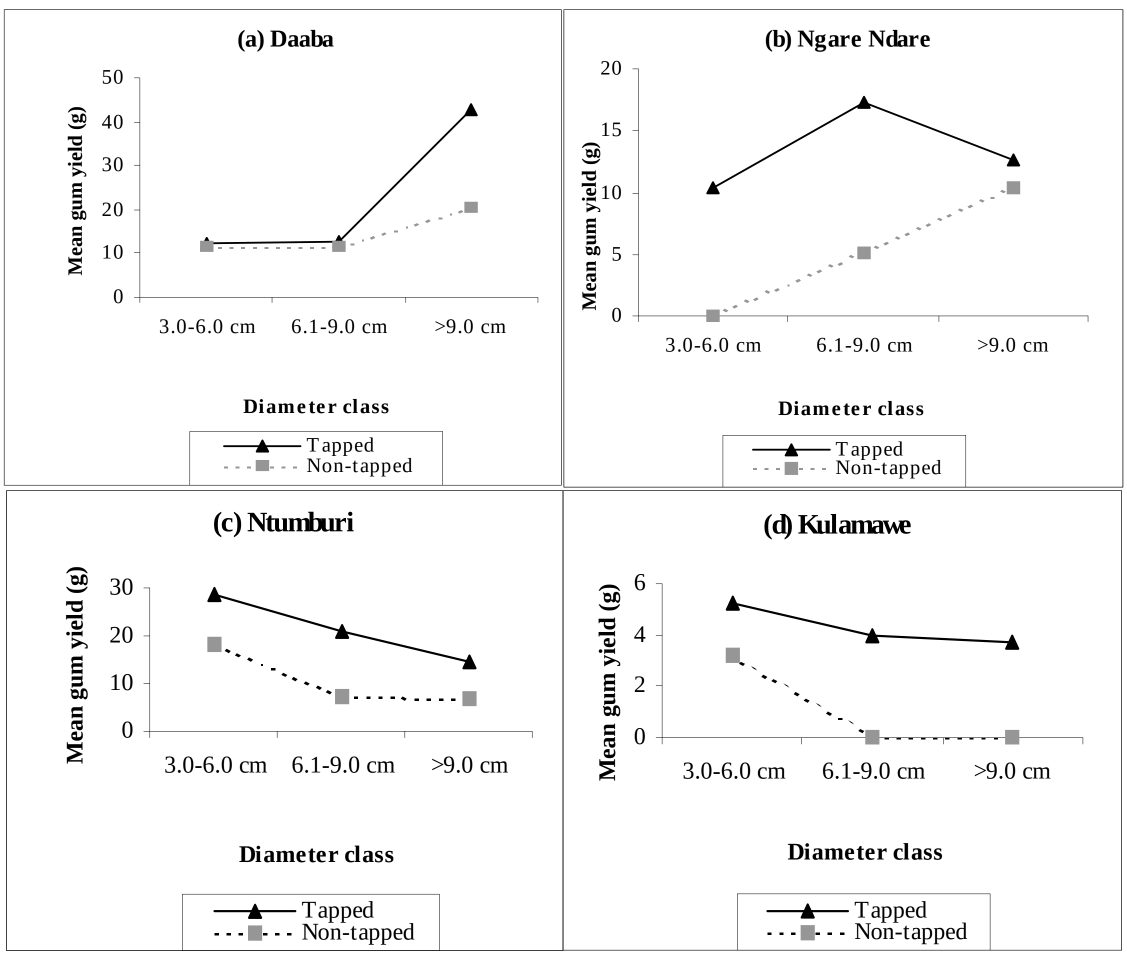

Figure 2. Influence of diameter class on gum yield in selected sites in Isiolo County, Eastern Province

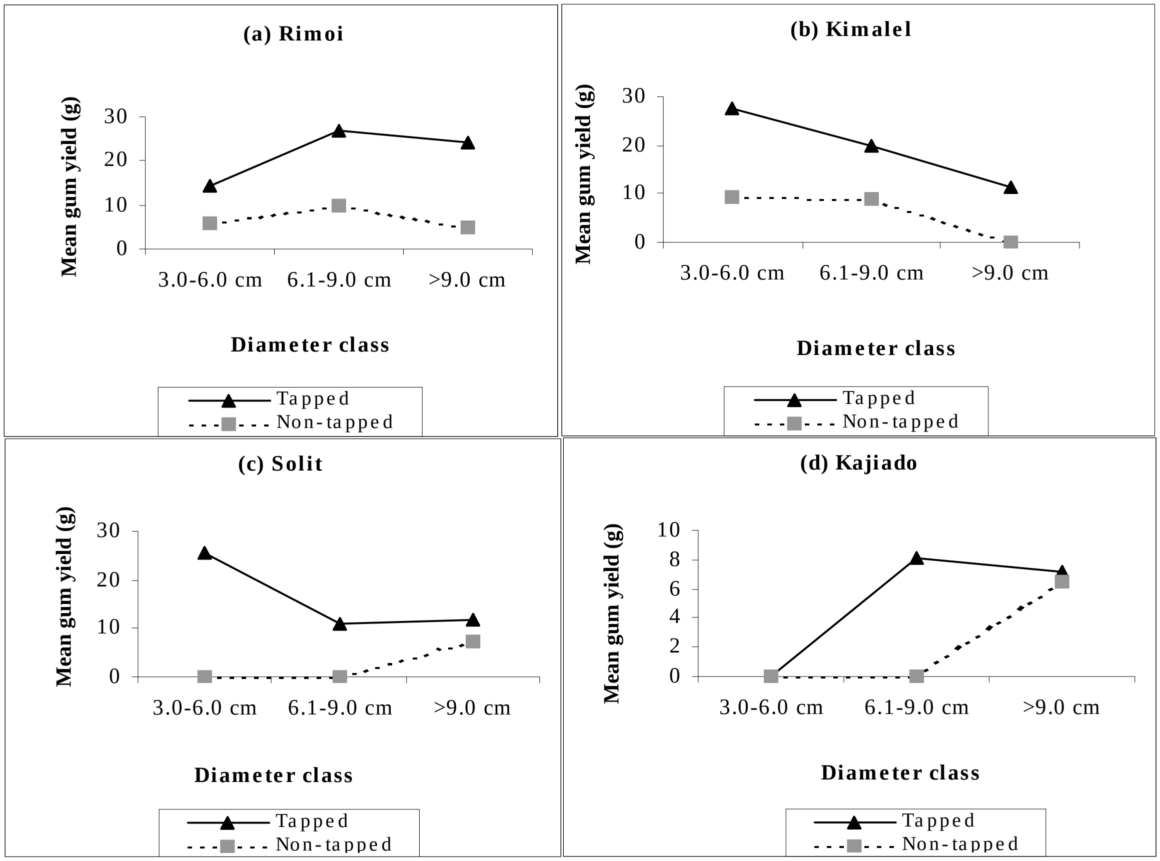

Figure 3. Influence of diameter class on gum yield in sites located in Baringo and Kajiado counties, Rift Valley Province (Rimoi, Kimalel and Solit are in Baringo County)

Table 2. Comparison of mean gum arabic yield per tree per season among three varieties of *A.senegal*

Site	Tapped			Non-Tapped		
	Diameter class (cm)			Diameter class (cm)		
	3.0-6.0	6.1-9.0	> 9.0	3.0-6.0	6.1-9.0	>9.0
DB	12.48a	12.90a	42.59a	11.33a	11.60a	20.33a
NN	10.42a	17.28a	12.60b	NP	5.14b	10.31b
NT	28.53b	21.06b	14.39b	18.38b	7.33b	6.67c
KM	5.24c	3.98c	3.72c	3.24c	NP	NP
RM	14.19a	26.86b	24.09d	5.62c	9.83a	5.11c
KL	27.48b	19.84b	11.55b	9.25a	8.77a	NP
SL	25.37b	10.91a	11.62b	NP	NP	7.47c
KJ	NP	8.08a	7.17c	NP	NP	6.45c

(*DB-Daaba, NN-Ngare Ndare, NT-Ntumburi, KM-Kulamawe, RM-Rimoi, KL-Kimalel, SL-Solit* and *KJ-Kajiado*)
*****Results marked with different alphabetical letters in the columns are significantly different ($p<0.05$)
NP- Non-productive trees that totally failed to produce gum during the entire assessment period.

As indicated in Table 2, no significant difference in yield was observed between Daaba and Ngare Ndare for diameter classes 3.0-6.0 cm and 6.1-9.0 cm under tapping conditions ($p<0.05$). Conversely, for diameter class greater than 9.0 cm, significant difference was detected in the mean gum yield for the tapped trees ($p<0.05$) in Daaba and Ngare Ndare which are predominantly occupied by *A. senegal* var. *kerensis*. Considering untapped trees in Daaba and Ngare Ndare, the mean gum yield was significantly different ($p<0.05$) across the three diameter classes (Table 2). In fact, at Ngare Ndare, untapped trees falling under diameter class of 3.0-6.0 cm did not yield gum at all for the entire assessment period. Further comparisons ($p<0.05$) were made for gum yield from tapped *A. senegal* var. *kerensis* at Kimalel in Baringo County with Daaba and Ngare Ndare in Isiolo County (Table 2). By and large, tapped trees (3.0-6.0 cm and 6.1-9.0 cm basal diameter classes), produced higher quantities of gum in Kimalel than Daaba and Ngare Ndare. However, the gum productivity in Kimalel was lower in trees with diameter >9.0 cm compared to trees of similar diameter in Daaba and Ngare Ndare.

A different scenario was observed for untapped *A. senegal* var. *kerensis* in Kimalel, Daaba and Ngare Ndare (Table 2). Untapped trees in Kimalel and Ngare Ndare produced less gum than in Daaba across all the diameter classes. High yields of gum were recorded in Kimalel than Ngare Ndare for trees that were not tapped in diameter classes 3.0-6.0 cm and 6.1-9.0 cm. On the contrary, untapped trees in diameter class >9.0 cm at Ngare Ndare produced more gum than at Kimalel. Gum produced by tapped *A. senegal* var. *senegal* did not vary in Ntumburi and Solit for trees of diameter class 3.0-6.0 cm ($p<0.05$) as indicated in Table 2. However, the quantity of gum produced by similar variety in Rimoi significantly differed from Ntumburi and Solit and was lower. Trees (*A. senegal* var. *senegal*) in the same diameter class for Kajiado site did not produce any gum at all and hence was exceptional in comparison with the rest of the sites. Tapped trees in diameter class 6.1-9.0 cm, did not show significant difference in gum yield in Ntumburi and Rimoi ($p<0.05$). Similarly, Solit and Kajiado were not significantly different. The production of gum in this diameter class (6.1-9.0 cm) was lower in Solit and Kajiado than Ntumburi and Rimoi. On average, the highest gum production in this diameter class (6.1-9.0 cm) was recorded in Rimoi. Gum produced by tapped *A. senegal* var. *senegal* with basal diameter >9.0 cm in Solit and Ntumburi compared well and did not vary ($p<0.05$). Tapped trees in this diameter class (>9.0 cm) in Rimoi yielded more gum than Solit and Ntumburi. Regarding yield of gum by untapped *A. senegal* var. *senegal* and for diameter class 3.0-6.0 cm, trees in Ntumburi produced more gum followed by Rimoi whereas Kajiado and Solit registered the least yield levels. On the other hand, trees left untapped in the diameter class 6.1-9.0 cm in Rimoi yielded the highest amount of gum followed by Ntumburi. Untapped *A. senegal* var. *senegal* trees in Kajiado and Solit in diameter class 6.1-9.0 cm totally failed to produce gum. Hence, a highly significant variation ($p<0.05$) in gum productivity was evident for the two diameter classes (3.0-6.0 and 6.1-9.0 cm) in the four sites for untapped *A. senegal* var. *senegal* trees. Nevertheless, untapped trees with a girth >9.0 cm showed no significant difference in the gum yield among the four sites occupied by *A. senegal* var. *senegal* ($p<0.05$). Since gum arabic production potential of *A. senegal* var. *leiorhachis* was assessed in only one site, comparison could only be made with other two varieties studied. Generally, the quantity of gum collected from *A. senegal* var. *leiorhachis* was considerably lower compared with the other varieties (*A. senegal* var. *senegal* and *A. senegal* var. *kerensis*). This was observed across all the diameter classes for both tapped and non-tapped trees. The maximum gum yield of 5.2g per tree per season produced by *A. senegal* var. *leiorhachis* was very low compared to 64.0g (var. *kerensis*) and 91.0 (var. *senegal*) respectively. Therefore, from these results, it was authoritatively established that *A. senegal* var. *leiorhachis* has very low potential for exploitation of gum for commercial purposes.

Minimum, maximum and range values of gum arabic yield by 3 varieties of *Acacia senegal*

Under tapping conditions, the highest yielding *A. senegal* var. *senegal* tree produced 91.0g per season while *A. senegal* var. *kerensis* had 64.7g per season (Table 3). *A. senegal* var. *leiorhachis*' highest producer tree yielded 5.2g per season which was merely 8.1% and 5.7% of highest producers of *A. senegal* var. *kerensis* and *A. senegal* var. *senegal* respectively. When the trees were not tapped, *A. senegal* var. *senegal* that produced the highest quantity of gum had 69.5g per season whereas *A. senegal* var. *kerensis* had 33.0g per season. The highest yielding untapped *A. senegal* var. *leiorhachis* tree had 3.2g in the seasons assessed representing a paltry 4.6% and 9.7% of high yielders of untapped *A. senegal* var. *senegal* and *A. senegal* var. *kerensis* respectively. Considering trees that produced the lowest amount of gum, the least amount of gum produced by *A. senegal* var. *kerensis* was 3.7g and 3.2g per season for tapped and untapped trees respectively. In the case of *A. senegal* var. *senegal*, the quantity was 3.3g and 2.8g per season for tapped and untapped trees respectively. The case of *A. senegal* var. *leiorhachis* was exceptional since the least producer trees were at the same time the highest yielders resulting into zero range values in both tapping and non-tapping conditions for selected trees that yielded measurable quantities of gum arabic.

Table 3. Minimum, maximum and range values of Gum Arabic yield by three varieties in sites

Site	Class (cm)	Tapped			Non-Tapped		
		Min.	Max.	Range	Min.	Max.	Range
DB	3.0-6.0	4.8	43.6	38.8	8.5	16.7	8.2
	6.1-9.0	3.7	32.8	29.1	4.3	29.9	25.6
	>9.0	10.7	64.7	54.0	3.2	33.0	29.8
NN	3.0-6.0	5.0	32.3	27.3	NP	NP	NP
	6.1-9.0	6.1	18.7	12.6	5.1	5.1	0
	>9.0	6.1	18.9	12.8	4.7	29.9	25.2
NT	3.0-6.0	11.9	53.2	41.3	4.0	69.5	65.5
	6.1-9.0	4.1	58.0	53.9	3.4	12.8	9.4
	>9.0	3.7	24.7	21.0	3.3	11.0	7.7
KM	3.0-6.0	5.2	5.2	0	3.2	3.2	0
	6.1-9.0	4.0	4.0	0	NP	NP	NP
	>9.0	3.7	3.7	0	NP	NP	NP
RM	3.0-6.0	3.5	40.2	36.7	3.4	8.6	5.2
	6.1-9.0	4.7	91.2	86.5	3.4	30.0	26.6
	>9.0	5.3	86.4	81.1	2.8	6.5	3.7
KL	3.0-6.0	7.2	51.4	44.2	3.9	17.6	13.7
	6.1-9.0	3.8	45.4	41.6	7.9	9.6	1.7
	>9.0	4.2	17.8	13.6	NP	NP	NP
SL	3.0-6.0	4.1	83.8	79.7	NP	NP	NP
	6.1-9.0	3.4	25.4	22.0	NP	NP	NP
	>9.0	3.3	36.8	33.5	7.5	7.5	0
KJ	3.0-6.0	NP	NP	NP	NP	NP	NP
	6.1-9.0	3.9	14.6	10.7	NP	NP	NP
	>9.0	3.4	17.1	13.7	3.4	15.4	12.0

NP- Non-productive trees that totally failed to produce gum during the entire assessment period
(*DB-Daaba, NN-Ngare Ndare, NT-Ntumburi, KM-Kulamawe, RM-Rimoi, KL-Kimalel, SL-Solit* and *KJ-Kajiado*)

Different varieties yielded varying quantities of gum. The amount of gum produced by the three varieties of *A. senegal* also varied with diameter size classes. It was established that small sized *A. senegal* var. *senegal* in Ntumburi and Solit and *A. senegal* var. *leiorhachis* trees with a diameter range of between 3.0 and 6.0 cm produced higher quantities of gum than trees with diameters greater than 6.1 cm. As the basal diameters of tapped and untapped *A. senegal* var. *senegal* and *A. senegal* var. *leiorhachis* trees increased, the gum yield decreased. In Kenya, individuals of naturally growing *A. senegal* var. *senegal* aged between 7 and 12 years have been found to exhibit basal diameter range of between 4.2 and 5.4 cm. Therefore, the *A. senegal* var. *senegal* trees in diameter size class range of 3.0-6.0 cm which produced high quantities of gum than their counterparts in diameter classes 6.1-9.0 cm and >9.0 cm fall within this age bracket of 7 to 12 years. Previous studies by

Wekesa *et al.,* (2009), ITC (1983), Abdel (2001) indicated that gum yield increases up to the age of 15 years, before it levels off and then begins to decline after the gum trees attain the age of 20 years. Moreover, NAS (1979) and Duke (1981) reported that the highest yield has been observed in individual of *A. senegal* var. *senegal* trees aged from 7 to 12 years as confirmed in this particular study. The gum yield trends too varied between and among *A. senegal* var. *senegal* varieties. The yield trend for *A. senegal* var. *senegal* in Rimoi was different from Ntumburi and Solit. In Rimoi, *A. senegal* var. *senegal* trees occurring within diameter class of 6.1-9.0 cm yielded high quantities of gum while those in the diameter class 3.0-6.0 cm produced the smallest amount. On the other hand, the yield trend in Ntumburi and Solit was such that as the diameter size class increased, the amount of gum produced by individual trees decreased. This difference in the yield trend could be attributed to individual tree differences as reported by Chikamai (1997). Some of the selected *A. senegal* var. *senegal* trees within diameter class 6.1-9.0 cm could be natural high yielders. Hence, although they are assumed to be older than trees selected from diameter class range of 3.0-6.0 cm, their production potential was comparatively higher. *A. senegal* var. *kerensis* in Kimalel showed a decreasing trend in the amount of gum produced as the diameter size class increased for both tapped and untapped trees. This trend is similar to what was observed in Ntumburi and Solit for *A. senegal* var. *senegal*. This accentuates the fact that younger trees (smaller diameter) produces high quantities of gum than older trees (larger diameter) as earlier reported Wekesa *et al.,* (2009, 2010). Clearly, there was high variability in gum production for *A. senegal* var. *kerensis* among the sites and diameter size classes as indicated by the variability in the yield trends. The gum yield trend for *A. senegal* var. *kerensis* in Daaba was directly opposite of Kimalel. The quantity of gum produced in Daaba increased with increasing tree diameter size class. This variability in gum yield trends and hence production observed in *A. senegal* var. *kerensis* could be attributed to genetic variations. According to Omondi *et al.,* (2010), most of the genetic variation in *A. senegal* var. *kerensis* in Kenya is partitioned within (91.0%) rather than among (9.0%) of the populations as is characteristic of an outcrossing tree species. Hence, Kimalel, Ngare Ndare and Daaba being considered as different populations of *A. senegal* var. *kerensis*, the closeness to each other of mean gum yield values and hence the trends in yield in certain diameter classes of both tapped and untapped trees can be attributed to the genetic variation partitioning of *A. senegal* var. *kerensis* among populations. On the other hand, the significant variation in mean gum productivity and trends in yield for trees within selected diameter size classes can be attributed to the genetic variation partitioning of *A. senegal* var. *kerensis* within populations resulting from individual tree differences (Chikamai, 1997). Genetic variability brings about dissimilarities in individual trees and hence incongruities witnessed in productivity (Omondi *et al.,* 2010).

Soil physical characteristics seem to have a gigantic impact on gum production especially when the trees are not induced through tapping for *A. senegal* varieties *kerensis* and *senegal*. Soil moisture has an effect on the yield of gum with low soil moisture favouring increased gum production (Gaafar *et al.,* 2006; Raddad and Luukkanen, 2007). Soil moisture is a function of the amount of water retained or available in the soil which is dependent on the soil textural characteristics. Thus, the difference in soil physical characteristics in the sites explains the sharp differences in yields among the sites. Soils in Ntumburi, Rimoi, Kimalel and Daaba are sandy-loam while in Ngare Ndare they are rocky and sandy. Sandy-loam soils have good water retention ability compared to rocky-sand soils implying that *A. senegal* var. *kerensis* in Kimalel and Daaba and *A. senegal* var. *senegal* in Ntumburi and Rimoi are able to absorb and accumulate sufficient water which is used in formation of reserve carbohydrates in hydrophilic form from which gum is formed. In contrast, gum-producing trees in Ngare Ndare, Solit and Kajiado experience limited water availability due to poor water holding capacity exhibited by rocky and sandy soils resulting into less hydrophilic reserve carbohydrates being formed. Gum formation has been regarded as a natural response of trees under dehydration stress to store a strongly hydrophilic form of reserve carbohydrate and therefore, gum yield is directly proportionate to the reserve carbohydrate in hydrophilic form formed within the plant by cambial cells of the inner bark (Anderson, 1995). Generally, tapping increased yield (gum production) by about 47.1%, 91.8% and 85.7% for trees occurring in diameter size classes 3.0-6.0 cm, 6.1-9.0 cm and >9.0 cm respectively. On average, tapping increased gum production by 74.9% irrespective of the size (diameter class) of the tree. Results of previous studies (Wekesa *et al.,* 2009) indicated that tapping increased yield by 77.4% and this has been confirmed by the present findings. Agriculture Research Co-operation of Sudan (ARCS) has also reported that tapping coupled with good management increases gum production by 47-60%, which is close to the results obtained in this particular study.

In terms of yield, *A. senegal* var. *senegal* trees produced as high as 91.2g of gum per tree in one season. This quantity of 91.2g per tree per season compares well with a mean value of 99.2g per tree per season earlier reported for farmer managed natural stands of *A. senegal* var. *senegal* (Ballal *et al.,* 2005). *A. senegal* var. *kerensis* highest producer tree had 64.7g per season which was higher than 0.81g per tree per season as previously found by Chiveu *et al.,* (2009). The highest reported yield obtained from an individual tree of *A. senegal* var. *leiorhachis* in Kulamawe of 3.05g per tree per season (Wekesa *et al.,* 2009) was about 58.7% of the highest yield from an individual tree in current findings which was 5.2g per tree per season. Previous reports have indicated that the yield of gum from an individual trees range from a few grams to 10 kg (NAS 1979, Dagnew 2006). Therefore, our results confirms the findings by NAS (1979) and Dagnew (2006) and goes a step further to state that the yield range for three Kenyan varieties combined is 3.3-91.2g and 2.8-69.5g per tree per season for tapped and untapped trees respectively. In most of the diameter classes, *A. senegal* var. *senegal* ranked higher than *A. senegal* var. *kerensis* and *A. senegal* var. *leiorhachis* in average gum yield per tree per season. However, a combined average of both tapped and untapped trees in the three diameter classes gave *A. senegal* var. *kerensis* a high mean value of gum yield per tree per season followed by *A. senegal* var. *senegal*. *A. senegal* var. *leiorhachis* was ranked last. Therefore, *A. senegal* var. *kerensis* remains the main source of commercial gum in Kenya (Chikamai and Banks, 1993).

CONCLUSION

Age and/or tree size was found to be a critical factor that influences gum yield in naturally growing *A. senegal* varieties. The size and age of *A. senegal* influenced gum arabic yield per individual tree per season for *A. senegal* var. *senegal* and *A. senegal* var. *leiorhachis* with trees in basal diameter class 3.0-6.0 cm producing more gum than their counterparts in diameter classes 6.0-9.0 cm and >9.0 cm. But, the size and age did not seem to have any pronounced effect on the quantity of gum produced by *A. senegal* var. *kerensis*. Tapping increased gum production by between 47.1 and 91.8% depending on the variety and diameter class. Specifically, tapping enhanced the yield of gum by 47.1%, 91.8% and 85.7% for trees occurring in diameter classes 3.0-6.0 cm, 6.1-9.0 cm and greater than 9.0 cm respectively. On average, tapping increased gum production by about 74.9% irrespective of the basal diameter of the tree under consideration. Comparatively, *A. senegal* var. *kerensis* produced high quantities of gum than *A. senegal* var. *senegal* and *A. senegal* var. *leiorhachis*. Consequently, different varieties yield varying quantities of gum. The amount of gum produced by *A. senegal* var. *senegal* and *A. senegal* var. *kerensis* varied among sites for the different diameter classes and did not show a clear-cut pattern. Soil physical properties particularly the textural formation likely affects gum production. Apart from variety differences, site edaphic conditions and tapping, this study indicated that intrinsic tree characteristics exhibited by individual trees also influenced the gum yield.

Acknowledgements: The authors would like to thank EU through Acacia Gum Project for funding the study. The logistical support received from KEFRI that hosted the project is highly appreciated. We also thank the field data collection crew of Mary Gathara, Samuel Kamonde and Abdi Somo for doing a fantastic job. The input of the statistician Enock Kiplagat is highly acknowledged. Thank you to all others who contributed towards the development of this manuscript in one way or another.

REFERENCES

Abdel RHM. (2001). Effect of some growth parameters and age on gum and seed yield of Acacia senegal plantations and natural stands in North Kordofan. MSc. thesis, Faculty of Forestry, University of Khartoum, Sudan. pp 73.

Anderson DMW (1995). Gums -Ancient and modern commercial products. NFT Highlights NFTA 95-01, Winrock International, Arkansas, USA.

Anderson DMW, Weiping PW. (1992). Gum Arabic (*Acacia senegal*) from Uganda: characteristics N.M.R spectra, amino compositions and gum/soil cationic relationships. Int. Tree Crop J. 7(3):167-179.

Arce LR, Banks H. (2001). A preliminary survey of pollen and other morphological characters in neo-tropical *Acacia* subgenus Aculeiferum (Leguminosae: Mimosoideae). *Bot. J. Linn. Soc*.135: 263-270.

Badi KHM, Ahmed AE, Bayoumi AMS. (1989). The Forests of the Sudan, Khartoum. Agricultural Research Council, Sudan, pp. 148.

Ballal ME, EL Siddig EA, Elfadl MA, Luukkanen O. (2005). Gum Arabic yield in differently managed A. senegal stands in western Sudan. Agro-forestry Forum 63:237-245.

Beentje HJ.(1994). Kenya Trees, Shrubs and Lianas. Nairobi: National Museums of Kenya. pp 722.

Cheema MSZA, Qadir SA. (1973). Autecology of Acacia senegal (L.) Willd. Vegetation. 27(13):131-162.

Chikamai BN. (1997). Production, markets and quality control of gum arabic in Africa: Findings and recommendations from an FAO project. *In*: Mugah JO, Chikamai BN, Mbiru SS and Casadei E (Eds.), Conservation, management and utilization of plant gums, resins and essential oils. Proceedings of a regional conference for Africa, 6-10th October 1997, Nairobi.

Chikamai BN, Banks WG. (1993). Gum Arabic from Acacia senegal (L) Willd. in Kenya.Food Hydrocolloids 7(6):521-534.

Chiveu JC, Dangasuk OG, Omunyin ME, Wachira FN. (2009). Quantitative variation among Kenyan populations of Acacia senegal (L.) Willd for gum production, seed and growth traits. New Forests, DOI 10.1007/s11056-008-9128-1.

Dagnew Y. (2006). Population status of *Acacia senegal* (L) Willdenow and its gum quality in the central rift valley of Ethiopia. MSc Thesis. The Department of Farm Forestry, Wondo Genet College of Forestry, School of Graduate Studies Awassa University, Awassa, Ethiopia. pp 77.

Duke JA. (1981). Handbook of legumes of world economic importance. Plenum Press. New York.

FAO. (1978). Forestry for local community development. Forestry Paper 7. FAO, Rome, Italy. pp. 114

FAO. (1999). Compendium of food additive specifications addendum 7. Food and nutrition paper, No. 52. Add. 7. Joint FAO/WHO Expert Committee on Food Additives 53rd Session Held in Rome, 1st - 10th June 1999. Rome: Food and Agriculture Organization of the United Nations.

Gaafar AM, Salih AA, Luukkanen O, Elfadl MA, Kaarakka V. (2006). Improving the traditional Acacia senegal-crop system in Sudan: the effect of tree density on water use, gum production and crop yield. Agro-forestry Systems 66:1–11.

Gachathi FN. (2002). Commercial Gum and Gum Resin Resources. In Chikamai, BN and Odera, JA. (Eds.), 2002 Commercial Plant Gums and Gum Resins in Kenya. Sources of Alternative Livelihood and Economic Development in the Drylands of Kenya. Executive Printers. Nairobi-Kenya.

ICRAF. (1992). A selection of useful trees and shrubs for Kenya: Notes on their identification, propagation and management for use by farming and pastoral communities. ICRAF.

ITC. (1972). The marketing of the principal water-soluble gums in the producing countries and in the United States, the United Kingdom, France and the Federal

Republic of Germany. International Trade Centre (ITC), Geneva, Swiss.

ITC. (1983). The gum arabic market and the development of production. International Trade Centre, UNCTAD/GATT, Geneva and the United Nations Sudano-Sahelian office.

Maundu PM, Ngugi GW, Kasuye HC. (1999). Traditional food plants of Kenya. Nairobi, Kenya.

Muthana KD. (1988). Gum arabic-the backbone of Kordofan Region, Sudan. My forest 24(2): 95–98.

NAS. (1979). Tropical legumes: Resources for the future. Report of an Ad Hoc Panel of the Advisory Committee on Technology Innovation, Board of Science and Technology for International Development, Commission on International Relations, National Research Council. National Academy of Sciences, Washington, D.C., USA. pp 331.

Obua J, Agea JG, Namirembe S, Egadu SP, Mucunguzi, P. (2006). The potential of *Acacia senegal* for dryland agroforestry and gum arabic production in Uganda. J. Drylands, 1: 186-193.

Okunomo K, Bosah BO. (2007). Germination Response of *Acacia senegal* (Linn) Seeds to Various Pre-sowing Treatments in the Nursery. Agricultural Journal, 2:681-684.

Omondi FS, Kireger E, Dangasuk OG, Chikamai BN, Odee DW, Cavers S, Khasa DP. (2010). Genetic Diversity and Population Structure of *Acacia senegal* (L) Willd. Kenya. Tropical Plant Biology 3(1): 59-70.

Raddad Ey, Luukkanen O. (2007). The influence of different *Acacia senegal* agro-forestry systems on soil water and crop yields in clay soils of the Blue Nile region, Sudan. Agricultural Water Management 87(1):61-72.

Raddad EY, Salih AA, Elfadl MA, Kaarakka V, Luukkanen O. (2005). Symbiotic nitrogen fixation in eight Acacia senegal provenances in dry land clays. Plant Soil. 27(5): 261-269.

Von Maydell HJ. (1990). Trees and shrubs of the Sahel: their characteristics and uses. Pp. 525

Wekesa C, Makenzi PM, Chikamai BN, Lelon JK, Luvanda AM, Muga M. (2009). Gum arabic yield in different varieties of Acacia senegal (L.) Willd in Kenya. African Journal of Plant Science 3(11):263-276.

Wekesa C, Makenzi PM, Chikamai BN, Luvanda AM, Muga M. 2010. Traditional Ecological Knowledge Associated with Acacia senegal (Gum arabic tree) Management and Gum Arabic Production in Northern Kenya. International Forestry Review. 12 (3):240-246.

White F. (1983). The Vegetation of Africa. UNESCO. Paris pp. 356.

Source of Support: None.
Conflict of interest: None. Declared.