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RADIOCARBON INVESTIGATION OF TWO LARGE AFRICAN BAOBABS FROM KIZIMKAZI, ZANZIBAR, TANZANIA

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ABSTRACT. The article reports the AMS (accelerator mass spectrometry) radiocarbon dating results of Kizimkazi Big tree and Kizimkazi II baobab, two large African baobabs from Zanzibar, Tanzania. Unfortunately, both baobabs toppled and died in 2018 and 2020, during violent storms. The investigation of the two baobabs evinced that the first of them, which was also the biggest tree of Tanzania, consisted of 5 stems, out of which 2 were false ones, and had a closed ring-shaped structure. The second baobab was composed of 4 fused stems and had a cluster structure. Several wood samples were collected from the two baobabs. Seven segments were extracted from the samples and dated by radiocarbon. The oldest segment from Kizimkazi Big tree had a radiocarbon date of 312 ± 18 BP, corresponding to a calibrated age of 380 ± 10 calendar years. According to dating results, the Kizimkazi Big tree died at the age of 400 ± 25 years. The oldest segment from Kizimkazi II baobab had a radiocarbon date of 137 ± 17 BP, corresponding to a calibrated age of 190 ± 10 calendar years. This value indicates that the Kizimkazi II baobab was 250 ± 25 years old when it died.

Keywords: *AMS radiocarbon dating, Adansonia digitata, dendrochronology, age determination, multiple stems, false cavity.*

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INTRODUCTION

The *Adansonia* genus, which belongs to the Bombacoideae subfamily of Malvaceae, is represented by six species endemic to Madagascar, one species restricted to NW Australia and one or two species distributed throughout the tropics of mainland Africa. The African baobab (*Adansonia digitata* L.) is the best known and widespread of the eight or nine *Adansonia* species. The African baobab is endemic to the arid savanna of mainland Africa between the latitudes 16º N and 26º S. It can also be found on several African islands and outside Africa, in different areas throughout the tropics, where it has been introduced [1-6].

In 2005, we started an extended research project to elucidate several controversial aspects concerning the architecture, growth and age of the African baobab. This research is based on a new approach, which is not limited to fallen specimens, but allows to investigate and date live individuals, as well. Our approach consists of AMS radiocarbon dating of tiny wood samples collected especially from inner cavities, deep incisions/entrances in the stems, fractured stems and from the exterior of large baobabs [7-17]. According to the research results, all large and old baobabs are practically multi-stemmed and exhibit preferentially closed or open ring-shaped structures. The oldest specimens were found to reach ages up to 2,500 years [14].

Since 2013 our investigations include also large and old individuals of the three best-known species of Madagascar, i.e., *Adansonia za* Baill. (Za baobab), *Adansonia rubrostipa* Jum. & H. Perrier (Fony baobab) and *Adansonia grandidieri* Baill. (Grandidier baobab) [18-22].

Zanzibar is an archipelago in the Indian Ocean, 36 km off the east coast of Africa. It is formed by two main islands, Zanzibar (or Unguja) and Pemba, plus over 50 smaller islands.

Over the centuries, Zanzibar has been visited and occupied by traders, explorers and settlers. In 1840, the Sultan of Oman transferred the seat of his Government to Zanzibar. In 1890, the British proclaimed Zanzibar a protectorate. Zanzibar became an independent state in December 1963, but only for a short time. In April 1964, Zanzibar formed an Union with Tanganyika under the name of the United Republic of Tanzania. Today, Zanzibar is still a semi-autonomous region of Tanzania [23].

The climate of Zanzibar is tropical, hot all year around, with two rainy seasons, known as the “long rains” season (March to May) and the “short rains” season (mid-October to December). The annual rainfall can reach 1600 mm in Zanzibar Island and 1900 mm in Pemba.

Zanzibar has a large population of African baobabs, with many big individuals. The baobabs grow especially in Zanzibar Island and Pemba.

According to our estimate, only Zanzibar Island hosts between 1 and 2 million individuals. The baobabs are mainly concentrated in the south-west and south-east, in the central area around Zanzibar Town and in the north-west. Here we present the investigation and AMS radiocarbon dating results of two very large baobabs from Kizimkazi, Zanzibar Island.

RESULTS AND DISCUSSION

The investigated baobabs and their areas. Kizimkazi is located on the south-western coast of Zanzibar Island. It consists of two villages, just down the road from each other. The most important is Kizimkazi Mkunguni (also known as Kizimkazi Mtendeni), a fishing village with a wide beach, new guesthouses and beachfront hotels. The second village, Kizimkazi Dimbani, is located several kilometres to the north and was once a walled city. It is the site of the Shirazi Mosque, the oldest mosque in Zanzibar with inscriptions dating back to 1107 [23]. Kizimkazi hosts many large baobabs, out of which 7 trees have girth values over 15 m. Unfortunately, the two largest trees, which we called Kizimkazi Big baobab and Kizimkazi II baobab, toppled and died recently.

Figure 1. General view of the Kizimkazi Big tree in 2015, taken from the east.

The Kizimkazi Big tree and its area. The impressive baobab was located in Kizimkazi Mkunguni at a distance of only 80 m from the ocean shore. The GPS coordinates are 06º27.209' S, 039º28.298' E and the altitude is 4 m. The mean annual rainfall in the area is 1147 mm, while the mean annual temperature reaches 26.4 °C (Zanzibar Town/Kisauni station). The Big tree had a maximum height of 21.8 m, the circumference at breast height (cbh; at 1.30 m above ground level) was 22.38 m and the overall wood volume was around 310 m^3 (**Figures 1 and 2**). The horizontal dimensions of the canopy were 35.5 (NS) x 46.5 (WE) m. In terms of volume, this baobab of Kizimkazi Mkunguni was the biggest tree not only in Zanzibar, but also in the whole Tanzania. The Kizimkazi Big tree toppled and died during a violent tropical storm in December 15, 2020.

Figure 2. View of the Kizimkazi Big tree taken from the west. The two investigated samples KBT-1 and KBT-2 were collected from the large stem in the centre of the image and from the false stem on the right.

The Big tree consisted of 5 stems, out of which 2 were false stems, which provided a better stability in sandy soils [24]. According to dating results, the baobab exhibited a closed ring-shaped structure [11, 14], with a false cavity defined by three stems, which was completely closed. This architecture was confirmed in December 2020, when the Big tree split (**Figure 3**) before it collapsed completely (**Figure 4**).

The Kizimkazi II baobab and its area. The second largest baobab of Kizimkazi in terms of girth was located in a private garden of Kizimkazi Dimbani. The GPS coordinates are 06º26.812' S, 039º25.485' E and the altitude is 16 m. The baobab had a maximum height of 22.2 m, the circumference at breast height was 20.45 m and the overall wood volume was around 180 m^3 (**Figures 5**). The horizontal dimensions of the canopy were 25.5 (NS) x 23.3 (WE) m. The baobab had a cluster structure and consisted of 4 perfectly fused stems. The Kizimkazi II baobab also toppled and died due to very strong winds during the monsoon in April 12, 2018.

Figure 3. The Kizimkazi Big tree split during a violent storm in December 2020, revealing the false cavity inside its multi-stemmed trunk.

Figure 4. The Kizimkazi Big tree collapsed totally several days after the violent storm.

Figure 5. General view of the Kizimkazi II baobab. The investigated sample KIIB-1 was collected from the stem on the right of the image.

Wood samples. Two wood samples were collected from the exterior of each baobab with an increment borer.

One sample, labelled KBT-1, with the length of 0.80 m, was collected from the largest stem of the Kizimkazi Big tree, at the height of 1.97 m. A number of four tiny pieces/segments, each 10^{-3} m long (marked from a to d), were extracted from determined positions of sample KBT-1. Another sample, labelled KBT-2, was collected from the deepest end/origin of the biggest false stem, at the height of 2.12 m. One segment (marked x) was extracted from this sample.

Two other samples, labelled KIIB-1 and KIIB-2, with the length of 0.78 m and 0.26 m, were collected from two stems of the Kizimkazi II baobab, at heights of 2.10 and 2.03 m. The second sample KIIB-2 was too short for investigation. Therefore, we investigated only the first sample KIIB-1, from which we extracted two tiny segments (marked a and b) from determined positions.

AMS results and calibrated ages. Radiocarbon dates of the seven sample segments are listed in Table 1. The radiocarbon dates are expressed in ^{14}C yr BP (radiocarbon years before present, i.e., before the reference year 1950). Radiocarbon dates and errors were rounded to the nearest year.

Table 1. AMS Radiocarbon dating results and calibrated ages of samples collected from the Kizimkazi Big tree (KBT) and from the Kizimkazi II baobab (KIIB).

Sample code	Depth[1] [height[2]] (m)	Radiocarbon date [error] (^{14}C yr BP)	Cal CE range 1σ [confidence interval]	Assigned year [error] (cal CE)	Sample age [error] (cal CE)
KBT-1a	0.30 [1.97]	154 [± 20]	1696-1724 [16.0%] **1834-1890 [35.8%]** 1924-... [16.5%]	1862 [± 28]	160 [± 30]
KBT-1b	0.50 [1.97]	212 [± 20]	1671-1684 [12.3%] **1732-1782 [48.5%]** 1796-1804 [7.5%]	1757 [± 15]	265 [± 15]
KBT-1c	0.70 [1.97]	312 [± 18]	1516-1540 [22.5%] **1627-1652 [45.8%]**	1639 [± 12]	380 [± 10]
KBT-1d	0.80 [1.97]	257 [± 19]	**1650-1671 [41.9%]** 1782-1796 [26.4%]	1660 [± 10]	360 [± 10]
KBT-2x	0.50 [2.12]	230 [± 17]	1668-1673 [6.1%] **1739-1798 [62.2%]**	1764 [± 15]	255 [± 15]
KIIB-1a	0.40 [2.10]	95 [± 21]	1821-1830 [10.4%] **1892-1922 [57.9%]**	1907 [± 15]	110 [± 15]
KIIB-1b	0.78 [2.10]	137 [± 17]	1706-1720 [11.0%] **1813-1836 [19.1%]** 1850-1866 [11.7%] 1879-1896 [13.2%] 1904-1926 [13.3%]	1824 [± 10]	190 [± 10]

[1] Depth in the wood from the sampling point. [2] Height above ground level.

Calibrated (cal) ages, expressed in calendar years CE (CE, i.e., common era), are also displayed in Table 1. The 1σ probability distribution (68.3%) was selected to derive calibrated age ranges. For four segments (KBT-1c, KBT-1d, KBT-2x, KIIB-1a), the 1σ distribution is consistent with two ranges of calendar years, for two sample segments (KBT-1a, KBT-1b) it corresponds to three ranges and for one range (KIIB-1b) it corresponds to five ranges. In all these cases, the confidence interval of one range is considerably greater than that of the other(s); therefore, it was selected as the cal CE range of the segment for the purpose of this discussion.

For obtaining single calendar age values of sample segments, we derived a mean calendar age of each sample segment, called assigned year, from the selected range (marked in bold). Sample/segment ages represent the difference between the year 2020 CE (for samples KBT-1 and KBT-2, when the Kizimkazi Big tree died) or the year 2018 CE (for sample KIIB-1, when the Kizimkazi II baobab died) and the assigned year, with the corresponding error. Sample ages and errors were rounded to the nearest 5 yr. This approach for selecting calibrated age ranges and single values for sample ages was used in our previous articles on AMS radiocarbon dating of large and old angiosperm trees.

Dating results of samples. In the case of Kizimkazi Big tree, for the segments extracted from sample KBT-1, which was collected from the exterior, the age values increase from KBT-1a to KBT-1c, after which the age decreases to KBT-1d. This anomalous age sequence is characteristic to baobabs that possess a closed ring-shaped structure with a false cavity inside. In this architecture, for wood samples collected from the exterior of the trunk, as well as for samples collected from the inner cavity walls (if the false cavity has an accessible opening), the age sequence increases from the sampling point up to a point of maximum age, after which it decreases in the opposite direction [11, 14]. For sample KBT-1, segment ages show that the point of maximum age was located between the segments KBT-1c and KBT-1d, i.e., between 0.70 and 0.80 m from the sampling point. Therefore, the maximum age in the direction of sample KBT-1 was around 400 ± 25 calendar yr. The walls of the false cavity, which was defined by 3 fused stems and was completely closed toward the exterior, had a depth of 1.30-1.40 m.

The second sample KBT-2 originated from the largest false stem, namely close to its emergence from the adjacent ordinary stem. The age of segment KBT-2x, i.e., 255 ± 15 years, corresponds to the age of the false stem, which assured a better stability of the huge tree in the sandy soil [24].

For the Kizimkazi II baobab, the investigated sample KIIB-1 was collected from a deep incision (0.30 m) in a stem, at the height of 2.10 m above ground, where the circumference of the four-stemmed trunk was 17.60 m. According to these values, the diametre of the sampled stem at this height was 2.80 m and its theoretical pith was situated at 1.10 m from the sampling point. Consequently, the distance between the dated segment KIIB-1b, which was 190 ± 10 yr old, and the theoretical pith of the stem was 0.33 m. These values indicate an age of 250 ± 25 yr for the pith of the sampled stem, as well as for the Kizimkazi II baobab.

CONCLUSIONS

The research discloses the AMS radiocarbon investigation results of two very large African baobabs from Kizimkazi, Zanzibar Island, Tanzania, which we called Kizimkazi Big tree and Kizimkazi II baobab. The main aim of our research was to determine the architecture and the age of the two baobabs. Unfortunately, the two baobabs toppled and died in 2020 and 2018, due to violent storms with strong winds. Thus, they are added to the list of monumental baobabs from southern Africa which collapsed and died since 2005.

The Kizimkazi Big tree was composed of 5 stems, out of which 3 were ordinary and 2 were false stems. It exhibited a closed ring-shaped structure, with a false cavity inside which was completely closed. The oldest sample segment had a radiocarbon date of 312 ± 18 BP, which corresponds to a calibrated age of 380 ± 10 calendar yr. According to dating results, the Kizimkazi Big tree started growing 400 ± 25 years ago, while the largest false stem was 255 ± 15 years old.

The Kizimkazi II baobab consisted of 4 perfectly fused stems and had a cluster structure. The oldest sample segment had a radiocarbon date of 137 ± 17 BP, corresponding to a calibrated age of 190 ± 10 calendar yr. According to this value, the Kizimkazi II baobab had an age of 250 ± 25 years when it died.

The obtained dating results demonstrate that, due to the very high amount of precipitation, the baobabs of Zanzibar grow very fast and can reach very large dimensions at a young age.

EXPERIMENTAL SECTION

Sample collection. The wood samples were collected from the two baobabs with a Haglöf CH 800 increment borer (0.80 m long, 0.0054 m inner diameter). A number of seven segments of the length of 10^{-3} m were extracted from predetermined positions along the wood samples. The segments were processed and investigated by AMS radiocarbon dating.

Sample preparation. The standard acid-base-acid pretreatment method was used for removing soluble and mobile organic components [25]. The pretreated samples were combusted to CO_2 by using the closed tube combustion method [26]. Next, CO_2 was reduced to graphite on iron catalyst [27]. Eventually, the resulting graphite samples were investigated by AMS.

AMS measurements. AMS radiocarbon measurements were performed at the NOSAMS Facility of the Woods Hole Oceanographic Institution (Woods Hole, MA, U.S.A.), by using the Pelletron ® Tandem 500 kV AMS system. The obtained fraction modern values, corrected for isotope fractionation with the normalized $\delta^{13}C$ value of -25 $^{0}/_{00}$, were converted to a radiocarbon date.

Calibration. Radiocarbon dates were calibrated and converted into calendar ages with the OxCal v4.4 for Windows [28], by using the SHCal20 atmospheric data set [29].

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