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AMS RADIOCARBON DATING OF THE VERY LARGE PEDUNCULATE OAK OF CAJVANA

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ABSTRACT. Using a new approach of dating live angiosperm trees, three wood samples collected from the inner cavity of the very large pedunculate oak (*Quercus robur* L.) of Cajvana, Romania, were processed and radiocarbon dated by AMS for determining the age of the tree. The radiocarbon date of the oldest sample was found to be 736 ± 23 BP, which corresponds to a calibrated calendar age of 735 ± 10 years. By considering the original position of this sample in the hollow trunk, one can estimate that the age of the oak is around 810 years.

Keywords: *radiocarbon dating, accelerator mass spectrometry, dendrochronology, pedunculate oak, tree growth.*

INTRODUCTION

The pedunculate oak (*Quercus robur* L.), which belongs to the family Fagaceae, is considered to be one of the most longlived native European tree. The age limit of the pedunculate oak, based mainly on age estimates of the largest specimens, remains controversial. Modern tree researchers consider that the upper limit of its age could be close to 1,000 years [1, 2].

The age determination of large oaks is a very difficult task. A complete ring counting on remaining stumps of old dead specimens is usually not possible, due to the existence of large cavities in their trunks. The use of the size/diametre-age relation for oaks is very questionable and may generate large errors. Age estimates based mainly on ring counting or cross-dating of increment cores collected from the exterior of the trunk were done on several big live individuals. The obtained age values were extrapolated to the theoretical pith, which is assimilated to the geometric midpoint, according to different formulas which consider growth rate values based on research done on stumps and especially on younger live trees growing in somewhat similar conditions [3, 4]. Other estimates are based on growth rates determined by

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successive girth measurements of large individuals, performed over longer periods of time [1]. Even in such cases, the age estimate error, which remains unknown, can be important.

The radiocarbon investigation of wood samples represents the most accurate method for dating trees without a continuous sequence of growth rings in the trunk [5, 6]. Ages of the oldest radiocarbon dated samples are significantly greater than the relatively short tree-ring sequences of the increment cores collected from the exterior of the trunk; therefore, the necessary age extrapolation to the pith is less demanding in radiocarbon dating. Previously we determined the age of the dead historic pedunculate oak of Țebea, Romania, by radiocarbon dating of wood samples originating from the upper part of its trunk, which was removed [7]. Traditionally, radiocarbon investigation was limited to dating wood samples from the remains of dead or severely damaged trees. Recently, we extended considerably the possibility of ageing large angiosperm trees, by introducing a methodology which allows to date by radiocarbon standing and live specimens. This new approach is based on radiocarbon dating of wood samples collected from the inner cavities of live hollow trees [8].

Here we present and discuss the AMS (accelerator mass spectrometry) radiocarbon dating results of three wood samples collected from the cavity of the largest Romanian pedunculate oak, located in Cajvana.

RESULTS AND DISCUSSION

The pedunculate oak of Cajvana and its location

The Cajvana oak has a long history, handed down from one generation to the other. It is stated that in 1476 the prominent Prince of Moldavia, Stephen the Great (1457-1504), accompanied by his soldiers, stopped underneath the tree. However, the history of the oak is claimed to be much older. Residents of the area believe that the oak originates from time of the Tartar invasion of 1241. In this year, the entire male population of the settlement perished in the battle and was buried in a huge common grave. An oak was planted for marking the site; this would be the today's giant oak. In 1942, the Romanian Academy nominated the Cajvana oak as a Monument of Nature.

The city of Cajvana is situated in the NE part of Romania, in the centre of Suceava county, on the county road 178 D, at 36 km NW from Suceava. The city is crossed by the river Cajvana, which is a branch of the Soloneț river. The mean annual temperature in the area is 7.6 ºC and the mean annual rainfall is 579 mm (Suceava station). The large pedunculate oak (Figure 1) is located on a hill just in the centre of the city, at a distance of ca. 120 m from the Cajvana river. Its GPS coordinates are 47º42.117' N, 025º58.072' E; the altitude is 399 m. The tree has a height of 20.1 m and a circumference at breast height (cbh; 1.30 m above ground level) of 11.01 m, which corresponds to a formal diametre (dbh) of 3.50 m.

The large trunk, which has an almost cylindrical shape, divides at the height of 3.45 m into two heavy branches with basal diametres of 1.85 and 1.75 m (Figures 2 and 3), which rises quasi-vertically and divide further forming a large canopy. The maximum dimensions of the canopy are of 22.4 m (in NE-SW direction) and 18.8 m (ca. 25 m before 2006, when a large secondary branch was cut; in NW-SE direction). A volume estimate indicates a total wood volume of around 85 m^3, out of which 35 m^3 for the trunk, 39 m^3 for the two large primary branches and 11 m^3 for the smaller branches. The volume was over 90 m^3 in 2006, when a long secondary branch, which extended just over the county road and was partially damaged during a storm, was cut for security reasons.

Figure 1. General view of the large oak of Cajvana taken from the south, during summer time.

In present, the tree is in a stage of decline, which started over a century ago. An investigation across the trunk revealed that three primary and several large secondary branches are missing; they broke off during storms and heavy winters or were cut by the local people. Around 1870, the tree was hit by lightning, it burst into flames and a part of the canopy broke off; a large vertical mark along the biggest primary branch testifies to this event. According to local sources, over the first half of the 20th century the canopy was still twice larger than it is today and it was also significantly taller.

Figure 2. View of the oak of Cajvana taken from the east, showing its trunk and branches at the end of autumn.

Consequently, we estimate that the overall wood volume of the Cajvana oak was once around 140 m^3; this value is close to the volume of the oak of Ivenack, Germany, which is considered to be the largest in Europe [1, 3]. According to the above values, the tree of Cajvana is one of the biggest European oaks and the largest pedunculate oak in south-eastern Europe.

Figure 3. The image taken from the west shows the trunk and the two remaining primary branches of the Cajvana oak.

As of today, the percentage of dead and dry branches in the remaining canopy is of over 15 %. The county road, located at only 10 m distance from the oak, is getting the busier and busier; the upgrading of the road around 1985 required cutting a large root. In addition, no speed limit is enforced and no weight limit is imposed on truck trailers in the proximity of the old tree. All these factors likely sped up the decline of the oak.

The trunk has a large bell-shaped cavity, which extends vertically up to the second largest branch, reaching the height of 3.81 m. The cavity base at ground level is quasi-ellipsoidal, with the length of the two axis of 2.24 and 1.82 m. Somewhat surprisingly, the big cavity has a small opening/ entrance toward east, with a width of only 0.23 m and a height of 0.50 m; however, these dimensions of the entrance are sufficient for allowing a skinny person to access the inside of the cavity (Figure 4) wood at the surface of the cavity walls is partially rotten, showing that the cavitation process is still in progress.

Figure 4. The image shows the trunk of the Cajvana oak, with the small entrance to the cavity

Three small wood samples collected from the cavity were pretreated and investigated by AMS radiocarbon analysis.

AMS results and calibrated ages

Fraction modern values and radiocarbon dates of the three samples are presented in Table 1. Radiocarbon dates and errors were rounded to the nearest year. Calibrated (cal) ages, which were derived directly from fraction modern values, are also listed in Table 1. The 1-σ probability distribution was selected to calculate calibrated age ranges. For sample 2, the 1-σ distribution corresponds only to one range. For sample 1 and 3, the 1-σ distribution corresponds to several ranges of calendar years. In this case, the confidence interval of one range (marked in bold) is much greater than of the others; therefore, it was selected as the most probable cal AD range of the respective sample, for the purpose of this discussion.

For obtaining single calendar age values of samples, we derived a mean calendar age of each sample from the 1-σ range with the highest probability. Calendar ages of samples represent the difference between AD 2010 and the mean value of the selected 1-σ range, with the corresponding error. Calendar ages of samples and errors were rounded to the nearest 5 years.

Table 1. AMS dating results and calibrated calendar ages

Sample code	Height[1] [m]	Diametre[2] [m]	Fraction modern [error]	Radiocarbon date [error] (^{14}C yr BP)	Cal AD range(s) 1-σ [confidence interval]	Sample age [error] (cal yr)
1	1.20	3.30	0.9621 [± 0.0033]	310 [± 26]	**1521-1577 [45.8%]** 1582-1591 [6.1%] 1621-1642 [16.3%]	460 [± 30]
2	0.90	3.58	0.9125 [± 0.0029]	736 [± 23]	**1263-1284 [68.2%]**	735 [± 10]
3	0.30	3.68	0.9822 [± 0.0030]	144 [± 24]	1678-1696 [10.3%] **1726-1765 [22.2%]** 1772-1776 [2.0%] 1800-1814 [8.1%] 1837-1844 [2.9%] 1852-1876 [9.2%] 1918-1940 [13.7%]	265 [± 25]

[1] Height of sample above ground level.
[2] Diametre of the trunk at sampling height.

Dating results of samples

The three samples were collected from the cavity at different heights above ground, according to the cavity shape and to the profile of walls. Even if the trunk is quasi-cylindrical from ground level up to breast height, there are some diametre differences, according to height and direction. The maximum and minimum diametre values at 1 m above ground are of 3.78 and 3.22 m. The diametre at sampling height was considered to be the diametre of the trunk which passes by the geometric/symmetry centre of the trunk at this height and the sampling point. The sample heights and the diametres at sampling height are shown in Table 1. The cross-section of the trunk at 1 m above ground, showing also the inner cavity and the sampling positions is displayed in Figure 5.

The black bark has a thickness of 4-10 cm, with a mean value of ca. 6 cm. We used this value for calculating the three trunk diametres inside bark at sampling height, which are 3.18, 3.46 and 3.56 m. Mention should be made that the dated segment of each sample originates from a distance of 3 cm (for sample 1 and 2) and 5 cm (for sample 3) inside wood from the sampling point.

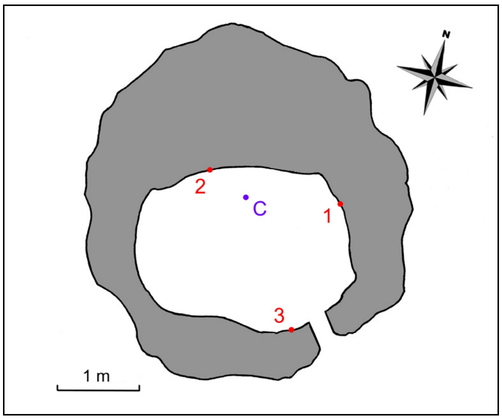

Figure 5. Schematic cross-section of the Cajvana oak's trunk (at 1 m above ground; bark included), showing the inner cavity, the positions of the sampling points (labeled 1, 2 and 3) and the geometric/ symmetry centre of the trunk (noticed by C). As a reference, the entrance to the cavity is also shown, even if it has a height of only 0.50 m.

The radiocarbon dates of the three samples were found to be of 310 ± 26, 736 ± 23 and 144 ± 24 BP (radiocarbon years before present, i.e. before AD 1950). These values correspond to calibrated calendar ages of 460 ± 30, 735 ± 10 and 265 ± 25 years.

Growth rates

For each sample, we calculated the distances from the dated segment to the bark and to the geometric centre of the trunk, respectively. For calculating and comparing growth rate values of the trunk, measured by the increase in radius, we converted all these values for a mean diametre of the trunk at breast height dbh = 3.50 m, which corresponds to a dbh value inside bark of 3.38 m and to a radius inside bark of 1.69 m.

In this case, the distances from the dated segments of the three samples to the bark are of 0.68, 1.30 and 0.32 m, while the distances to the geometric centre are 1.01, 0.39 and 1.37 m. By considering also the ages of the three samples, one can state that the radial increase of the trunk of Cajvana oak was of 0.32 m over the past ca. 265 years, 0.68 m over the past ca. 460 years and 1.30 m over the past ca. 735 years.

Age of the tree

For determining the age of the investigated oak one should extrapolate the age of the oldest sample, i.e. sample 2, to the geometric centre of the trunk at the respective height. As mentioned above, the converted distance from the dated segment of sample 2 to the geometric centre is 0.39 m. Therefore, for calculating the age of the tree, one should add to the age of sample 2 (735 ± 10 years) the time needed by the trunk for growing from 0 to a radius of 0.39 m, i.e. a diametre dbh = 0.78 m.

Since it started growing, the oak of Cajvana has probably been a solitary tree, without competition in its close proximity. According to research done in Europe at comparable latitudes on solitary pedunculate oaks, growing in open conditions [9] and also to our research in Romania done on several stumps of isolated oaks and on live oaks of known age, we estimate that the time needed to the oak of Cajvana to reach a dbh of 0.78 m was 75 ± 15 years. One can also add a maximum additional error of ± 50 years, due to assigning the geometric centre of the trunk to the pith. Consequently, the final age value for the oak of Cajvana becomes 810 ± 75 years. One can state that the tree started growing around AD 1200, more precisely in the time frame 1125 – 1275.

Therefore, the dating results do not exclude the claim of the area's residents that the oak was planted in 1241, for marking the cruel Tartar invasion. On the other hand, the obtained dating results suggests that the oak of Cajvana could be even older than this historic date.

CONCLUSIONS

Using our new approach of dating live angiosperm trees, three samples were collected from the cavity of the large pedunculate oak of Cajvana, Romania, and investigated by AMS radiocarbon dating. According to the age of the oldest dated sample, i.e. 735 ± 10 years, the tree of Cajvana becomes one of the oldest pedunculate oaks with accurate dating results. By considering the position of the oldest sample in the trunk, the calculated tree age is 810 ± 75 years. This value is practically similar to that we determined for the historic pedunculate oak of Țebea, which died in 2005 [7]. The obtained results confirm that Romanian oaks can live to ages exceeding 800 years.

Given that the majority of old oaks develop open hollows in their trunks [10], this approach can be used on the large scale for getting accurate age estimates of big live specimens.

EXPERIMENTAL SECTION

Measurements. The external measurements of the tree and the measurements inside the cavity were performed by using a Bosch DLE 70 Professional laser rangefinder and graduated tapes.

Sample preparation. The standard acid-base-acid pretreatment method [11] was used to remove soluble and mobile organic components. The resulted cellulose samples were combusted to CO_2, by using the closed tube combustion method [12]. Then, CO_2 was reduced to graphite on iron catalyst, under hydrogen atmosphere [13]. Eventually, the graphite samples were analyzed by AMS.

AMS measurements. Radiocarbon measurements were carried out at the National Ocean Sciences AMS Facility of the Woods Hole Oceanographic Institution, with the Pelletron ® Tandem 500 kV AMS. The surface of the graphite samples was sputtered with cesium ions and the secondary negative ions were extracted and accelerated in the AMS system. ^{12}C and ^{13}C ions were measured in Faraday cups, where a ratio of their currents was recorded. Simultaneously, ^{14}C ions were recorded in a solid state detector, so that instantaneous ratios of ^{14}C to ^{12}C were also recorded. The raw signals were compared to ratios obtained with a known standard material (Oxalic Acid I, NIST-SRM-4990) and converted to a fraction modern value. Fraction modern values, corrected for isotopic fractionation with the normalized $\delta^{13}C$ value of -25 $^0/_{00}$, were converted to radiocarbon dates, expressed in years BP [14].

Calibration. Fraction modern values were calibrated and converted into calendar ages with the OxCal v4.1.5 for Windows [15], by using the IntCal09 atmospheric data set [16].

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