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2

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27 **Abstract:**

28 The olive tree was an iconic plant for most of the past Mediterranean civilizations, for
29 which it had important economic values. Here, we report the earliest use of fruits and wood
30 from olive trees in Africa so far, around 100,000 years ago. These findings suggest the presence
31 of olive trees in the Atlantic coast of Morocco during most of the last glacial, and the use of
32 olives by the early *Homo sapiens* for fuel management and most likely for consumption.

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52 **Main Text:**

53 Across the Mediterranean Basin, two varieties of olive trees (*Olea europaea*) exist: a wild
54 *O. europaea subsp. europaea* L. var. *sylvestris* and a cultivated *O. europaea subsp. europaea*
55 L. var. *europaea*. The oldest wild olive findings were recovered at the Acheulean site Gesher
56 Benot Ya'aqov (Israel), dating back to ca. 790 ka (1; ka: kiloanni). Since then, few
57 archaeological evidence has been retrieved (2-5): ca. 62–55, 49 and 43-41 ka in Greece, Israel
58 and Spain, respectively. From ca. 30 ka onwards, archaeological occurrences of olive remains
59 rather rare until the Epipalaeolithic (4, 6). It is only from the Neolithic onwards that wild olives
60 were intensively used by Mediterranean human groups, for the direct use of the entire tree (e.g.
61 food, fuel, lighting, medicine and cosmetics) and its conceptualization in mythology and
62 religion (7, 8). The olive was one of the first cultivated trees ca. 6 ka ago owing to its valuable
63 oil derivatives from its fruit (9).

64 The sporadic use of wild olives during the Palaeolithic may be due to its scarcity or absence
65 in the vegetation. However, DNA analyses and species distribution modelling (10)
66 demonstrated the capacity of the wild olive to survive the last glacial period in the
67 Mediterranean, although its presence would have been confined to refuge zones (4, 10, 11).
68 One of the largest refuge zones were probably situated on the Atlantic coasts of Morocco and
69 the southern part of the Iberian Peninsula (Fig. 1). Here, we present a ca. 100-ka-old evidence
70 of the presence of wild olives during the last glacial period in the Rabat-Temara region of
71 Morocco (Fig. 1).

72 In the Rabat-Temara region, El Mnasra and El Harhoura 2 caves were discovered in 1956
73 and 1977, respectively (Extended Data Fig. 1). Archaeological material from the Middle Stone
74 Age (MSA; from ca. 120 ka) and Iberomaurusian (Late Stone Age, LSA) is preserved in these
75 caves (12, 13). The findings from the MSA correspond to the Aterian culture with
76 Levallois/micro-Levallois debitage, side scrapers and the presence of tanged tools (tanged tools

77 only in El Mnasra). Bone tools associated with the Aterian culture have also been recovered at
78 El Mnasra. The Aterian MSA groups at El Mnasra showed some cultural originalities; they
79 produced the largest known *Nassaridae* perforated shells in Africa and used pigments such as
80 hematite. Human remains were discovered in the Aterian MSA levels at both sites. These
81 stratified coastal sequences with well-preserved successions of Aterian MSA occupations are
82 rare in North Africa, and the Rabat-Temara caves are thus of crucial importance for our
83 understanding of the evolution and dispersal of early *Homo sapiens* within and outside Africa
84 (12).

85 Early *Homo sapiens* are considered hunter-gatherers. The animal and lithic remains found
86 in archaeological contexts provide information about the hunter behaviour. However, the
87 findings corresponding to the gatherer behaviour (i.e. collect of plants) are uncommon for the
88 Palaeolithic, in particular those related to human diet and plant processing (14, 15, 16). In order
89 to recover plant remains at our sites, a specific methodological approach has been used (12) to
90 optimize the extraction of poorly preserved plant materials. Thus, charcoal (both sites) and
91 charred seed fragments (El Mnasra) from the Aterian MSA levels were recovered (Extended
92 Data Table 1; 12). Seventy-two percent of all charcoal fragments were identified as *Olea*
93 *europaea* (12); they can be attributed to the wild variety of *Olea europaea* by considering the
94 ages of the corresponding cultural levels. Due to the poor preservation of the plant remains
95 (12), twenty-four percent of the charcoal fragments can only be identified as dicots, which
96 includes wild olive and other wood taxa. The remaining charcoal fragments (4% of the
97 fragments) are determined as *Quercus sp.* (evergreen oak), *Juniperus/Tetraclinis* and
98 *Phillyrea/Rhamnus*. Regarding the seed fragments, eighty-one percent of all fragments are
99 charred olive stones (Extended Data Table 1); sixteen percent cannot be identified due to their
100 poor preservation. Wild olive stones were identified based on their morphology which strongly
101 resembles their modern counterparts (Fig. 2). Charcoal from wild olive was also found in an

102 Aterian MSA combustion feature at the nearby Contrebandiers site (12). This suggests the
103 widespread use of wild olives during the Aterian MSA in the Rabat-Temara region. Although
104 charcoal taphonomy needs to be considered carefully (12), there is no doubt that wild olives
105 were used by prehistoric hunter-gatherers.

106 Optically stimulated luminescence and combined U-series/Electron Spin Resonance dating
107 (12, 17) from Aterian MSA levels that include the plant fragments range from ca. 115 to 46 ka
108 (Extended Data Table 1). Accelerator Mass Spectrometry dating of a selection of charred olive
109 stones and olive charcoal fragments confirms that the ages of these samples are beyond the
110 limits of radiocarbon dating (> 50 ka) for El Mnasra and near the limit for El Harhoura 2 (12).

111 The sole presence of seed fragments in the Aterian MSA levels does not necessarily mean
112 that olive fruits were consumed. However, olive fruits are a key alimentary resource, and since
113 they are easy to collect, one can naturally assume that the Aterian MSA groups likely used the
114 fruits in their diet. One could argue that olive fruits may also have come attached to branches
115 which were used as fuel. The charred olive stones would have therefore resulted from an
116 involuntary action. However, the use of entire branches with fruits and leaves as fuel would
117 not be efficient. Since dry fruits quickly fall off branches and thus, being lost before reaching
118 the fireplace, the material would have been used when it was freshly collected and burnt green.
119 Greenwood, however, has a high moisture content resulting in a lower heating value and high
120 pollutant content during combustion among other disadvantages of its burning properties (see
121 below). The species forms also hardwood which would make its collection by cutting difficult,
122 especially without specific tools. Finally, complete olive stones would have been recovered
123 when burnt on its branches. All this points to a conscious use of olive fruits for consumption at
124 El Mnasra.

125 It is not entirely clear why the olives stones were broken and charred, which raises
126 important questions about human subsistence strategies. A first hypothesis would be that the

127 fruit could have been crushed for consumption and the leftovers thrown into the fireplace to
128 avoid the accumulation of alimentary detritus. However, eating crushed fruits would be
129 difficult. A second hypothesis would be that after consuming the fruit, the stones were thrown
130 into the fire to eliminate alimentary waste. In that case, a mixture of fragmented (during
131 charring) and whole charred stones would have been recovered. Breakage via heat exposure
132 would have resulted in sharp fractures along the edges of the stones (18), because of the
133 splitting of the stones into two halves (19, 20). A third hypothesis would be a deliberate
134 breakage of the stones by humans after consuming the fruits. This would have resulted in an
135 almost total fragmentation without specific breakage patterns, as it was observed in our
136 samples.

137 The third hypothesis appears to be most plausible. However, why would humans have
138 crushed the stones after the consumption of olives? We assume that they used the stones to
139 create a residue to enhance combustion. Olive stones and their seeds have a high lignin and oil
140 content (21-22). Therefore, the crushed olive stone residue would result in a slow combustion
141 with long-lasting flames, favoured for cooking. When dried, the residue produces smokeless
142 flames (21), which is a major advantage for prehistoric groups living in caves. Furthermore,
143 olive wood is a good firewood by holding high heat for a long time. Wild olive (wood and
144 stones) may thus be related to fuel management here. The specific use of wild olive as fuel
145 could also be influenced by its abundance in the region. While oak and juniper are also good
146 combustibles and present in the landscape, they have not been much considered by the
147 prehistoric groups as only few charcoal fragments from these plants have been recovered.

148 Wood and fruits from wild olive trees were likely collected from the vegetation around
149 Rabat-Temara. Wild olive is an abundant evergreen sclerophyllous tree/shrub in the present-
150 day regional vegetation characterized by a thermo-Mediterranean bioclimate (12). Pollen
151 archives show that *Olea* was present in the Mediterranean vegetation since the Miocene and

152 survived the Quaternary glaciations (4, 23, 24). Our findings demonstrate the presence of wild
153 olive on the Atlantic coast in Morocco during the Aterian MSA and most of the last glacial
154 period. This region has already been considered as a refuge for animals during the glacial
155 period, such as the Algerian mouse (12).

156 There exists no other Aterian MSA archaeological sites for comparison so far. In northern
157 Morocco, the archaeobotanical remains recovered at Taforalt, Ifri el Baroud, Kehf el Hammar
158 and Ghar Cahal (25-29; Fig. 1) are much younger, i.e. from some 35 ka ago. There, it has been
159 shown that MSA and LSA groups used different species including *Juniperus/Tetraclinis*,
160 *Quercus* sp., *Pinus* sp., *Phillyrea/Rhamnus* and *Pistacia* sp. At Taforalt from ca. 15 ka onwards,
161 acorns from oak, pistachios and seeds from pine, juniper, legumes and wild grasses were found;
162 it is assumed that they were consumed (26, 27). These observations might underline two
163 different gathering behaviours between the Aterian MSA groups living from ca. 115-46 ka ago
164 in the Rabat-Temara region and the later MSA and LSA groups living from ca. 35 ka onwards
165 in northern Morocco. The first would be related to fuel management where a species-specific
166 selection of plants is considered due to their burning characteristics and/or their abundance in
167 the vegetation, as found in the case for the Rabat-Temara populations. The second would be
168 related to food consumption, for which a large variety of plants are used for the diet.

169 The early use of wild olives in Africa by Aterian MSA groups from ca. 100,000 years ago
170 might represent improvements in cooking, technological innovations for wood processing and
171 social organization, among other aspects. This finding provides new insights into the
172 understanding of Aterian MSA hunter-gatherer economies, and complete the story of the iconic
173 olive tree in the Mediterranean.

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177 **Methods:**

178 **Sampling strategy.** The recovery of archaeobotanical remains during the excavations was very
179 challenging at both El Mnasra and El Harhoura 2. In particular, since the charcoal fragments
180 ‘disintegrated’ as soon as they were in contact with water (12). Therefore, instead of using
181 water flotation, we followed a ‘dry sampling protocol’ to optimize the collection of
182 archaeobotanical remains. In a first step, all dark-colored objects (i.e. potential
183 archaeobotanical remains) observed during the excavation have been collected with their
184 coating sediments. These samples have been dried and sent to the laboratory (Laboratoire
185 écologie fonctionnelle et environnement (Université de Toulouse, CNRS, INPT, UPS, France)
186 for the extraction of archaeobotanical remains with a sieve of 0.25 mm mesh size and for
187 botanical identification. In a second step, the residual sediments (resulting from the excavation)
188 have been dried and gently sieved with a 1mm sieve mesh size. A visual inspection under a
189 stereomicroscope was performed on the dried-sieved sediments equal to or larger than 1 mm;
190 this to collect all visible dark-colored objects elements with the coating sediments that have
191 then been sent to the laboratory for sieving (0.25 mm sieve mesh size) and botanical
192 identification. The pros and cons of using the dry sampling *versus* the water flotation protocol
193 is discussed in the Supplementary Materials (12).

194 The potential archaeobotanical remains with their coating sediments correspond to spatially
195 dispersed combustion residues spread over the archaeological levels and combustion features
196 (12). These remains were essentially recovered during the 2009, 2010 and 2017 excavations
197 from the Aterian MSA and LSA levels and few were archived from previous excavations (2001
198 and 2004), which are also included in this study.

199 The present study focused on the Aterian MSA levels, for which a total volume of sediment
200 of 414 litres has been analyzed (Table S1); 162 litres correspond to the sediments of
201 combustion features and 252 liters to archaeological sediments retrieved from outside the

202 combustion features (Table S2). A detailed overview of the sediments analyzed per
203 archaeological level is given in Table S1. For comparison, the total volume of sediment
204 processed for the MSA-LSA archaeological site Taforalt (northern Morocco) is 561 litres
205 including both LSA and MSA levels (28).

206

207 **Observation of charcoal and seed fragments.** The anatomical wood characteristics of the
208 charcoal from the archaeological sites were analysed under a reflected light microscope (200x
209 to 500x magnification). Botanical identification was possible when the wood anatomy was
210 observed in three dimensions, i.e., cross or transverse, radial and tangential sections (12). For
211 comparison and aiding the identification modern *Olea europaea* charcoal reference samples
212 (Fig. S4) were produced by placing a piece of modern olive wood in an aluminium container,
213 which was covered by pure sand (e.g., Fontainebleau sand) and exposed to heat at 550 °C in
214 an oven. This approach mimics the burning process in fireplaces by avoiding the complete
215 combustion of samples as the supply of oxygen is limited.

216 Most charcoal samples contained high accumulations of iron oxides and minerals in the
217 vessels and parenchyma (Fig. S5; 12), which made the identification of the wood taxa difficult.
218 The charcoal fragments were chemically cleaned to improve the observation of the main
219 anatomical features. Oxalic acid solutions were used as they do not dissolve the carbonates
220 from the sediments which are incorporated in the wood structure of the charcoals and thus, no
221 mechanical stress is applied due to possible gas releases (i.e. CO₂) when using hydrochloric
222 acid solutions.

223 Fragments of seeds and stones were analysed under a stereomicroscope for botanical
224 identification (12). Modern stones from *Olea europaea* were used for comparisons with the
225 fossil findings (Fig. 2).

226 A selection of samples (fossil and modern; charcoal and stones from *Olea europaea*) was
227 analysed using a Scanning Electron Microscope (SEM) in order to observe anatomical details
228 of wood and olive stone morphological features (Fig. 2; Figs S4, S5 and S6).

229

230 **Dating of fragments of charcoal and charred olive stones.** Dating of the fragments of
231 charcoal and charred olive stones from Aterian MSA levels was expected to result in ages near
232 50-45 ka or >50 ka as samples are assumed to be older than the range of radiocarbon dating
233 (i.e., ca. 50 ka). This would confirm the contemporaneity of these findings and the
234 archaeological levels in which they were found.

235 A total of fourteen fragments of charcoal and olive stones were used for dating (Table S4).
236 Six Aterian MSA fragments correspond to charcoal and two to charred olive stones. For
237 comparison with more recent archaeological levels, five fragments from LSA and one from the
238 Neolithic were also dated.

239 Charred olive stones and charcoal fragments were prepared following the routine pre-
240 treatment acid-alkali-acid protocol at the radiocarbon lab (UMR 7209, AASPE) of the Museum
241 national d'Histoire naturelle (MNHN, Paris, France). Samples were pretreated using
242 hydrochloric acid (HCl, 1M, 20°C, 1h) to remove exogeneous carbonates and then rinsed with
243 MiliQ water. A few drops of sodium hydroxide solution (NaOH, 0.125 M, 20°C, 15 min) were
244 added to the MiliQ water to eliminate humic acids and then rinsed again with MiliQ. A final
245 HCl wash (1M, 1h) was applied to remove the remaining contamination from modern CO₂
246 taken up by alkali (NaOH). Samples were combusted at temperatures superior to 700 °C. CO₂
247 gas extractions were carried out using a carbon extraction line. Graphitization and AMS dating
248 were carried out at the *Laboratoire de Mesure du Carbone 14* (CEA, Saclay, France). Dates
249 were calibrated using IntCal20 and OxCal software.

250

251 **Statistics and Reproducibility.** Two hundred four fossil charcoal fragments and 55 seed
252 fragments from *Olea europaea* have been observed. They all show the same anatomical
253 characteristics. Three of the fossil seed fragments, four of the fossil charcoal fragments, two
254 modern olive seeds and one modern charcoal fragment from *Olea europaea* were observed by
255 using a scanning electron microscope, which resulted in the micrographs shown in figures 2b-
256 d, 2f-h and supplementary figures 4a-f, 5a-d, 6d. Each of the four charcoal fragments was
257 broken to create fresh surfaces to observe the anatomical features at the three anatomical wood
258 sections.

259

260

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265 help in 2017 during the sampling and all the scientific members of the Moroccan-French
266 project El Harhoura-Témara. We further thank the three anonymous reviewers for their
267 valuable comments.

268

269 **Author contributions:** Project conceptualization was initiated by L.M. and T.O. Identification
270 of plant macro-remains was performed by T.O. Sampling was carried out by L.M., E.B.A, E.C.
271 and R.N. Dating and faunal data were compiled by E.B.A., E.S., E.C. and C.F. Samples for
272 dating were prepared by E.B.A., A.Z. and O.T. Excavations were led by R.N. and M.E.H. SEM
273 images were taken and interpreted by A.S., W.K., L.M. and T.O. All authors have contributed
274 to the writing of the manuscript and approved the final version.

275

276 **Competing interests:** The authors declare no competing interests.

277

278

279 **Figure Legends/Captions (for main text figures):**

280 **Fig. 1. Location of the archaeological sites in Morocco and suitable areas for wild olive**
281 **tree growth during the last full glacial cycle in the Mediterranean. (A)** Location of the
282 Aterian Middle Stone Age and Iberomaurusian Late Stone Age sites cited in the text: 1) sites
283 in the Rabat-Temara region, 2) Ghar Cahal, 3) Khef el Hammar, 4) Ifri el Baroud and 5)
284 Taforalt. **(B)** Location of the Rabat-Temara sites. **(C)** Map of potential long-term refugia (red
285 colour), i.e., regions considered as continuously suitable for the growth of wild olive trees
286 during the last full glacial cycle (10). The names of El Harhoura 2 and El Mnasra caves are
287 highlighted in bold.

288 **Fig. 2. Morphological characteristics of a modern (wild) olive stone and of fragments of**
289 **a charred olive stone (sample E12-DYJSQ) found in the Aterian MSA level 7 at El**
290 **Mnasra. (A)** Modern stone (stereomicroscope). **(B) (F)** A furrow (SEM). **(C) (G)** Detailed
291 view of a furrow (SEM). **(D) (H)** Ladder-like structure in the furrow (SEM). **(E)** Fragment of
292 Aterian MSA charred olive stones (stereomicroscope). SEM: Scanning Electron Microscope.
293 Fu: Furrow. Note different scales.

294

295

296 **Data Availability:**

297 **Archaeobotanical material.** All data and code that are used in the main text and
298 supplementary materials are presented in the file Supplementary Information. The material is
299 housed at the Department of Botany of the University of Innsbruck, Austria.

300 **Pollen data.** The percentages of *Olea* pollen from three marine sedimentary cores (12) are
301 available in the PANGAEA database:

302 A4-M15627-3: <https://doi.pangaea.de/10.1594/PANGAEA.55037>

303 A3-M16004-1: <https://doi.pangaea.de/10.1594/PANGAEA.55039>

304 A2-M15669-1: <https://doi.pangaea.de/10.1594/PANGAEA.55038>

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