

Restitutio ab initio: Direct dating and isotopic evidence to evaluate the proxy reliability of intrusive archaeobotanical remains

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Abstract

Recovering archaeobotanical remains from archaeological contexts often entails substantial methodological challenges. Flotation and environmental sampling routinely yield charred seeds whose cultural attribution does not necessarily correspond to the stratigraphic position or inferred chronology of the deposits in which they occur. Direct radiocarbon dating frequently exposes marked discrepancies, demonstrating that intrusive seeds may derive from much later occupations than the layers that contain them. Such materials are commonly excluded from analysis, either because they are deemed intrusive or because their taxa are not otherwise attested in the archaeological period represented by the context. We argue, however, that within multi-stratified and multi-period sites—where different occupational phases have been explored with uneven intensity—intrusive carpological remains can constitute informative, and at times indispensable, proxies for reconstructing underdocumented episodes of site use, provided their chronological and taphonomic status is verified through direct radiocarbon and stable isotope analysis.

This study presents new radiocarbon and stable isotope data for charred millet grains recovered from the Gumelnița site in southeastern Romania. Two broomcorn millet (*Panicum miliaceum*) grains and one foxtail millet (*Setaria italica*) grain were directly dated, placing their presence in the second half of the second millennium BC and the beginning of the first millennium BC. The foxtail millet grain constitutes the earliest securely dated occurrence of this species in Europe. These results demonstrate that intrusive grains, when robustly identified through direct testing, can serve as reliable proxies for documenting later occupational or depositional events superimposed upon earlier archaeological layers.

1. Introduction

A proper understanding of past plant-body history requires correlation with archaeological contexts and chronology, an essential condition for tracking archaeological, palaeoecological, or archaeobotanical queries. By their structure and morphology, plant micro- and macro-remains preserve a wide range of information on human activities and past environments. However, their recovery depends strongly on the depositional setting and subsequent taphonomic processes. Thus, such archaeobotanical remains may occur in multiple archaeological features and survive through different preservation pathways—including waterlogging, charring, desiccation, mineralisation, or as impressions—each requiring carefully adapted sampling and collection strategies to minimise contamination and disturbance (Celant et al. 2015).

1.1. The contextual fragility of archaeobotanical ecofacts

Broader site formation research confirms that both vertical and horizontal shifts of archaeobotanical macroremains often mirror the same sedimentary and disturbance processes documented for other ecofacts, including gravity driven microstratigraphic deformation, compaction, and bioturbation, all well established in classic analyses of cultural and natural formation processes (Schiffer 1987) and in micromorphological studies showing vertical displacement and lateral drift of organic particles under repeated wetting, trampling, and fine scale sediment movement (Goldberg and Macphail 2006).

Whenever subsurface remains are detected, investigators must be aware of possible disturbances and the effects these processes may have had on the distribution and patterning of the artefacts. By their very nature, micro- or macro-botanicals can be especially prone to post-depositional movement. Understanding these processes is essential because each mechanism of soil disturbance can alter the spatial integrity of archaeological materials in different ways, shaping both horizontal and vertical distributions and complicating subsequent interpretation. The soils in which artefacts/ecofacts are buried are dynamic, not static. Archaeologists have become increasingly aware that mechanical and biological processes are constantly at work, altering and disturbing the soil and in many cases its constituent cultural remains. The degree to which the original horizontal and vertical positions of artefacts or ecofacts are altered depends on the type, intensity, and duration of post-depositional disturbance processes (Goldberg and Macphail 2006; Waters 1997). Different agents (e.g., mammals, insects, earthworms, etc.) burrow through the soil, transporting sediments, clasts, and, in many cases, artefacts. Plant root growth, along with root decay and tree fall, physically alter archaeological strata. Anthropogenic activities (e.g., earthmoving, excavation, construction, and agriculture) are common sources of disturbance to buried archaeological deposits. Gravity, wind, water, and events such as earthquakes or meteor impacts can have dramatic effects on the distribution and patterning of subsurface remains. The swelling and shrinking of clays, along with freeze-thaw cycles, can move objects vertically within soil profiles. If these situations are not recognised, interpretation errors may occur. Several authors have identified nine or ten distinct disturbance processes (Johnson and Stegner 1990; Wood and Johnson 1978). Other authors (e.g., Schweger 1985; Stein 1983) have since elaborated on and provided case-in-point examples of the mechanisms of disturbance and their effects. While any evaluation must take these processes into account, archaeobotanical ecofacts (alongside other microartifacts) may be differentially affected and more prone to vertical movement in a deposit, potentially producing a "false" stratigraphy (e.g., indicating an occupation zone where none exists). Typically, the contexts of archaeological sites have undergone some form of post-depositional disturbance. However, in most instances, disturbance processes have not completely destroyed a site's stratigraphic integrity, and accurate assessments can be made (Goldberg and Macphail 2006; Waters 1997).

Building on this, archaeobotanical criteria for identifying and excluding intrusive seeds emphasise the importance of taxonomic consistency, stratigraphic coherence, and contextual patterning, since atypical distributions or taxa known to infiltrate deposits through natural disturbance often signal intrusion rather than cultural deposition (Hillman 1981; Hubbard and Clapham 1992; Schiffer 1987; van der Veen 1992).

Together, these findings demonstrate that horizontal movement of carbonised seeds can occur independently of human behaviour, underscoring the need to integrate stratigraphic control with micro-sedimentological analysis when interpreting archaeobotanical distributions.

1.2. Millet significance

Millets are small-seeded cereals of the Poaceae family, well suited to arid and semi-arid environments due to their exceptional drought tolerance, short growing season, and adaptability to poor soils. As C4 plants, they possess a highly efficient photosynthetic pathway that enhances carbon fixation under conditions of high temperature and low moisture. Their rapid maturation—often within three months—allows for a supplementary summer harvest, providing a critical buffer in years of winter crop failure (FAO 2023).

Among the earliest domesticated species, broomcorn millet (*Panicum miliaceum*) and foxtail millet (*Setaria italica*) originated in northern China around 10,300-8,700 cal BP (Liu et al. 2012; Lu et al. 2009; Wang et al. 2017; X. Yang et al. 2012; Zhao 2011). Although millet remains have been reported in Neolithic and Eneolithic contexts across central and western Europe (Hunt et al. 2008; Zohary et al. 2012), radiocarbon dating has revealed that these often belong to much later periods (Motuzaite-Matuzeviciute et al. 2013). A large-scale dating programme has shown that broomcorn millet likely reached Europe by the 16th century BC, with widespread cultivation occurring during the 15th and 14th centuries BC (Filipović et al. 2020). The earliest securely dated presence is currently from Vinogradniy Sad in Ukraine, around the 17th century BC (Dal Corso et al. 2022; Pashkevych 2022).

In Romania, broomcorn millet has been reported at Late Neolithic and Chalcolithic sites, though these early finds are often limited and potentially intrusive, as they remain undated by radiocarbon methods (Cârciumaru 1996; Monah 2007). While millet was present during the Bronze Age, its widespread cultivation appears to have intensified from the Iron Age onwards, becoming common at Dacian sites with archaeobotanical evidence (Cârciumaru 1996; Ciută 2021; Garcia-Vazquez et al. 2025).

1.3. Current approach

Primarily, our resume research in 2017 at the Gumelnița eponymous site in Romania, with focus on the Neolithic-Chalcolithic sequences, has confronted us with a situation that lies at the intersection of the two issues outlined above. The first concerns the presence of potentially intrusive millet seeds in two Chalcolithic burials (Lazăr et al. 2020), an occurrence that is inconsistent with the established cultural and chronological framework for the appearance of millet in Europe and thus constitutes part of the broader taphonomic challenges highlighted in the literature. Through this approach, however, we aim to show that, in some circumstances, even such potentially intrusive artefacts or ecofacts—whether micro- or macro-remains—originating from adjacent archaeological horizons (vertically or horizontally) may, particularly at sites investigated only at low intensity or through limited test trenches, nonetheless function as meaningful proxy indicators for reconstructing archaeological and palaeoecological aspects of past human communities.

2. Material and methods

2.1. The archaeological site

The Gumelnița site (also known as Măgura Gumelnița or Măgura Calomfirescu) is well known as the largest tell settlement north of the Danube and as the eponymous site of the Gumelnița culture, part of the Kodjadermen–Gumelnița–Karanovo VI (KGK VI) Chalcolithic block of the late fifth millennium BC. It anchors a long tradition of archaeological research in Romania, extending from Vladimir Dumitrescu's investigations in the 1920s to the present, within a micro-region densely occupied by contemporaneous and later sites representing multiple archaeological periods (Dumitrescu 1924, 1925, 1966; Dumitrescu and Marinescu-Bîlcu 2001; Lazăr et al. 2017; Lazăr 2001; Șerbănescu 2009; Șerbănescu 1985). The site is located in southeastern Romania (Fig. 1a), on the left bank of the Danube River, just south of the confluence of the Argeș River with its tributary, Valea Mare (García-Vázquez et al. 2023; Lazăr et al. 2017, 2020; Lazăr et al. 2021; Lazăr 2001; Tafani et al. 2025).

The site is composed of the Middle Chalcolithic KGK VI tell-type settlement and two pair necropolises, along with an Early Chalcolithic occupation (Boian - Vidra phase), a Late Chalcolithic cemetery (Cernavoda II culture), a Bronze Age settlement (Tei culture), and occupations corresponding to the first Iron Age and to the 7th-11th centuries AD (Lazăr et al. 2020; Șerbănescu 2009; Șerbănescu 1985, 2022) (Fig. S1).

2.2. The excavations

The excavations at Gumelnița, in disciplinary terms, have been primarily directed towards investigating and clarifying the internal stratigraphy and development of the Chalcolithic sequence (Gumelnița culture / Kodjadermen-Gumelnița-Karanovo VI – KGK VI) at the tell settlement and its associated cemetery, while also extending research into the adjacent floodplain through coring and various forms of non-intrusive prospection. These investigations aim to reconstruct past palaeoenvironments and to correlate isotopic data from humans, fauna, and plants with the archaeological record (Lazăr et al. 2017, 2020). The Chalcolithic tell and the related necropolis cover period between 5041–3992 cal BC (Table S1) (Bem 2000; García-Vázquez et al. 2023; Lazăr et al. 2017, 2020; Mattila et al. 2023; Popescu et al. 2023). They have yielded a rich sequence of palaeoecological and archaeological proxies, including evidence of mixed farming, sophisticated ceramic production, early metallurgy, and long-distance trade alongside a reduce human mobility (García-Vázquez et al. 2023; Lazăr 2001; Lazăr et al. 2017, 2020, 2021).

In 2018, in the terrace sector, following a report by our colleagues from the Oltenița Museum (Romania), we identified an illegally excavated area in the vicinity of an abandoned pig farm, c. 340 m north of the zone where we were conducting archaeological excavations in the Chalcolithic cemetery) (Fig. S2). This recent pit measured roughly 110 × 30 m at the time of our observation (June 2018). However, the analysis of satellite imagery (Google Earth/Google Maps) indicated that it had been used as a source of fill for a longer period (Lazăr et al. 2019, 2020) (Fig. S3). Crucially, in 2015, our colleagues from Oltenița Museum had already documented several disturbed and partially destroyed features by this borrow pit, attributed to the Chalcolithic and Bronze Age sequences; among these was at least one complete crouched burial ascribed to the Gumelnița culture (Șerbănescu 2022).

In this area, we carried out an initial survey, including drone flights and geospatial mapping, followed by targeted fieldwork (Frujină et al. 2020; Lazăr et al. 2017, 2019, 2020, 2021; Stal et al. 2022, 2024). This led to the identification of several archaeological features: some preserved in an uncut profile, others situated in a zone where the mechanical excavation had been halted (Fig. S4), leaving a stepped surface between the contemporary ground level (0) and the base of the borrow pit (c. 2.8–3.8 m), at approximately 1.4–1.9 m depth. Our excavations in this sector brought to light a series of archaeological features attributed mainly to the Chalcolithic sequence (including burial M10 - Fig. S5, which was radiocarbon dated - Table S2). Likewise, the first batch of broomcorn millet grains analysed in this study derives from this context. The second assemblage of archaeobotanical macro-remains comes from the Chalcolithic burial M8 (Table S2; Fig. S6), which was uncovered in the main area of investigation of the cemetery.

The methodological protocol applied in this sector – combining microstratigraphic excavation, Haris Matrix recording (Fig. S7), with the systematic flotation of the entire pit/grave fills – enabled the recovery of a range of micro-artefacts, bone fragments, and archaeobotanical remains. Each sediment sample was collected in a

separate plastic bag, with a standard size (10 L) for each bag (with absolute coordinates measured) (Table S2).

2.3. Archaeobotanical remains

Plant remains were recovered during the 2017–2019 excavations at the Gumelnița site (Lazăr et al. 2017, 2020, 2021) from sediment samples collected from the grave fills. Each 10-L sample was processed by machine-assisted flotation in the Bioarchaeology Department of the “Vasile Pârvan” Institute of Archaeology. The flotation samples were sorted and examined under a stereomicroscope (Optika ST-50LED), and the botanical macroremains were identified using standard reference atlases (Bojňanský and Fargšová 2007; Jacomet 2006; Schoch et al. 1988).

A wide variety of plant taxa has been recorded from Chalcolithic contexts at the site, including both settlement and funerary features, with most remains originating from the tell (Lazăr et al. 2017, 2020, 2021). Cereals constitute the most diverse and abundant category, comprising both wild and domesticated species in the 2018 campaign (Table S4).

Broomcorn and foxtail millet grains were recovered through sediment flotation from two Chalcolithic graves (M8 and M10) (Tables 1 and S3). The radiocarbon dates of these graves (Table S2) place them in the second half of the fifth millennium BC (García-Vázquez et al. 2023; Lazăr et al. 2020). Because the presence of millet in such early contexts is exceptional—and would *prima facie* suggest a Chalcolithic attribution predating the accepted chronology for its arrival in Europe—the grains were selected for direct radiocarbon dating to clarify their contextual placement.

Broomcorn and foxtail millet grains were recovered through sediment flotation from Chalcolithic graves (M8 and M10) (Tables 1 & S4). The radiocarbon dates of this graves (Table S2) place them in the second half of the 5th millennium BC (Lazăr et al., 2020; García-Vázquez et al. 2023). Because the presence of millet in such early contexts is exceptional—and might, at first sight, appear to indicate a Chalcolithic presence of the crop seemingly earlier than its currently accepted arrival in Europe—the grains were selected for direct radiocarbon dating to clarify their contextual placement. In the case of samples from DET 80, where two grains were recovered; one was chosen for radiocarbon dating, and the other for stable isotope analysis.

These efforts to obtain radiocarbon determinations from carbonised archaeobotanical macroremains form part of a broader line of research that our team has been developing over recent years (Garcia-Vazquez et al. 2025; Golea et al. 2023).

Table 1
Context for broomcorn and foxtail millet grains
recovered from the Gumelnița site.

Lab ID	Code - Context	Species
P207	DET 60 - M8	<i>Panicum miliaceum</i>
P208	DET 78 - M10	<i>Setaria italica</i>
P209	DET 80 - M10	<i>Panicum miliaceum</i>
GUM-122	DET 80 - M10	<i>Panicum miliaceum</i>

2.4. Radiocarbon analysis

Three charred grains were selected for radiocarbon dating (Table 2), with analyses conducted at the LARA - Laboratory for the Analysis of Radiocarbon with AMS, University of Bern (Bern, Switzerland) and the Laboratory of Applied Nuclear Physics Department, IFIN-HH (Măgurele, Romania) (RoAMS). Sample pretreatment followed the laboratory's established protocol (T. B. Sava et al. 2019). Calibrations were performed using OxCal 4.4 (Bronk Ramsey 2009) and the IntCal20 calibration curve (Reimer et al. 2020)..

2.5. Stable isotopes analysis

One broomcorn millet grain from grave M10 (GUM-122) was selected for stable isotope analysis (Table 1). Based on previous FTIR-ATR testing of charred seeds from the Gumelnița site, only mild contamination with carbonates and nitrates was observed (García-Vázquez et al. 2023), and the same pretreatment protocol was applied (Vaiglova et al. 2014): 0.5 M HCl at 80°C for 30 min (or until effervescence stopped) followed by three rinses in ultrapure water. The sample was oven-dried to a constant weight and then subjected to isotope ratio mass spectrometry (IRMS) analysis.

IRMS was conducted at the Unit of Instrumental Techniques of Analysis (UTIA) of the Research Support Services (SAI) of the University of A Coruña (UDC), Spain, using a DeltaV Advantage mass spectrometer coupled to a Flash IRMS EA IsoLink CNS analyser. Reproducibility was better than $\pm 0.2\text{‰}$ for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$, and values were calibrated against international standards. Internal precision was verified using acetanilide, yielding a standard deviation of $\pm 0.15\text{‰}$ across 10 replicates. Given the sample's weight (0.567 mg), it was analysed once. Results are expressed in delta (δ) notation. Data analysis was performed in Past 4.14 (Hammer et al. 2001), with final graphical editing in Adobe Illustrator.

3. Results

3.1. Radiocarbon data

The millet grains analysed in this study were recovered from the sediment fills of Chalcolithic graves, although their radiocarbon determinations indicate substantially later chronologies (Table 2). Sample P207 was calibrated to a continuous range of 1125–818 cal BC (2σ , 95.4%). Sample P208 produced a dominant calibrated range of 1418–1107 cal BC (2σ , 93.1%), with minor additional probability at 1096–1080 cal BC (1.3%) and 1068–1056 cal BC (1.1%). Finally, sample P209 was calibrated to 1272–926 cal BC (2σ , 95.4%).

These results place P208 and P209 firmly within the second half of the second millennium BC, while P207 falls at the very end of the second millennium or into the earliest part of the first millennium BC. The millet grains analysed in this study were identified in the sediments of the excavation of Chalcolithic graves, although radiocarbon dating produced younger results (Table 1).

Table 2

Radiocarbon ages, calibrated 2σ intervals, and median calibrated dates for the directly dated millet grains.

Lab ID	Species	Lab Code	¹⁴ C	Calibrated date (2σ)	Median date ± σ
P207	<i>P. miliaceum</i>	RoAMS-5520.2	2809 ± 60	1125–818 cal BC (95.4%)	968 ± 82 cal BC
P208	<i>S. italica</i>	RoAMS-5521.2	3017 ± 60	1418–1107 cal BC (93.1%) 1096–1080 cal BC (1.3%) 1068–1056 cal BC (1.1%)	1260 ± 92 cal BC
P209	<i>P. miliaceum</i>	RoAMS-5522.2	2912 ± 60	1272–926 cal BC (95.4%)	1107 ± 91 cal BC

3.2. Stable isotopes results

The sample GUM-122 (*Panicum miliaceum*), from M10, yielded a δ¹⁵N value of 3.5‰ and a δ¹³C value of –10.3‰, with nitrogen and carbon contents of 2.9% and 56.2%, respectively, and a C:N ratio of 22.9 (Table 3).

Table 3
Stable isotope results for the millet grain GUM-122.

Lab ID	Species	%N	δ ¹⁵ N (‰)	%C	δ ¹³ C (‰)	C:N
GUM-122	<i>P. miliaceum</i>	2.9	3.5	56.2	–10.3	22.9

4. Discussion

4.1. Updating the chronology of millet in Romania

These new findings align with the timing of broomcorn millet’s introduction to Eastern Europe described in Filipović et al., 2020 (Fig. 2a). Comparable findings at other Romanian sites—such as Cornești, Măgura-Buduiasca, and Teleac— (Filipović et al. 2020; Motuzaite-Matuzeviciute et al. 2013) (Fig. S8) further support the arrival and integration of broomcorn millet into local agricultural systems during this period. Additionally, P208, the only *Setaria italica* grain analysed, confirms that both millet species were present in Romania by the 2nd millennium BC. As far as current evidence indicates, this represents one of the earliest secure datings of foxtail millet in Europe. An earlier occurrence has been reported at the site of Pichori, near the Black Sea coast in the western Caucasus (Fig. 1a), with radiocarbon dates ranging between 2011 and 1771 cal BC. These findings suggest that both broomcorn and foxtail millet were involved in the westward expansion of millet cultivation.

Radiocarbon results indicate a time frame that cover Late Bronze Age (P207) and Early Iron (P208-P209) (Table 2). Our archaeobotanical finds are located in the vicinity of the area where the Tei settlement (Late

Bronze Age) (Figs. S1 and S9) was previously reported (Leahu 2003; Morintz 1978; Șerbănescu 2009), and the first logical attribution would therefore be to this site (Text S1). In this interpretation, the intrusive ecofacts within the Chalcolithic context would originate from Bronze Age features destroyed during modern interventions affecting the area we investigated.

According to the established relative chronology, the Tei culture spans the Middle and Late Bronze Age and is generally understood to emerge from the Glina–Schneckenberg and Cernavodă–Foltești substrata. Its development extends across most of Muntenia, into regions east of the Danube, and briefly into southeastern Transylvania before being superseded there by the Sighișoara–Wietenberg culture (Leahu 2003). When aligned with absolute chronology, the Tei cultural sequence can be placed—based on the radiocarbon framework synthesized by Ștefan (2021) together with broader regional ^{14}C correlations—between roughly 2050 cal BC and 1200 cal BC, with Tei I/Cățelu Nou emerging shortly after 2050 cal BC, Tei II consolidating around 1900–1750 cal BC, Tei III/La Stejar flourishing between approximately 1750–1500 cal BC, and the later Tei IV–V horizons spanning ca. 1500–1300 cal BC and 1300–1200 cal BC respectively.

Correlation of our radiocarbon results (Table 1) within this chronological framework indicate the latest stages of the Tei cultural sequence align particularly well with the ^{14}C data obtained from the Gumelnița–Valea Mare terrace, especially the samples from context M10 (P208 & P209), where foxtail and broomcorn millet yielded calibrated ranges characteristic of the final Tei horizon. These values fall squarely within the 13th–12th century BC span attributed to the closing phases of Tei IV–V, providing independent support for the placement of the upper cultural horizons at Gumelnița–Valea Mare within the final centuries of the Tei cultural sequence as previously mentioned (Leahu 2003; Morintz 1978; Ștefan 2021).

Despite these chronological nuances, although our archaeobotanical intrusive ecofacts derive from Chalcolithic funerary contexts, the spatial pattern shown in the Fig. S9 suggests a plausible origin for the intrusive Bronze Age plant remains (P208 & P209) identified within grave M10. It lies immediately adjacent to the area where the Bronze Age settlement and probably it was most likely situated, and where upper layers were heavily disturbed or destroyed by the modern borrow pit. This contemporary intervention would have removed any overlying Bronze Age features, allowing their botanical material to move vertically and laterally into earlier stratigraphic levels. In this sense, the intrusive millet grains act as proxies for Bronze Age structures and activities now lost, providing evidence of agricultural practices, palaeoecological conditions, and aspects of subsistence behaviour that are otherwise absent from the archaeological record.

In contrast, Grave M8 lies well beyond the presumed Bronze Age settlement core (Fig. S10), and the ^{14}C determination obtained for sample P207 likewise indicates a later horizon than the intrusive ecofacts from M10 (P208–P209), placing it at the beginning of the Iron Age (Table 2). However, this part of the site yielded no Late Bronze Age or Early Iron Age materials during our systematic excavations between 2017 and 2023. Only small Late Iron Age (La Tène) features were documented in this area during the 1960s (Marinescu-Bilcu 1962), and no earlier deposits were identified. The Romanian Cartographic Server and the National Archaeological Record, however, indicate the presence of Early Iron Age (Basarabi-period) material approximately 2.5 km north-west of the Gumelnița necropolis at the multi-layered site of Oltenița–Coadă Lupului (Fig. S10 and Supplementary Text S2), which constitutes the nearest securely attested context from which such intrusive grains might derive. In a broader Early Iron Age radiocarbon horizon of southeastern

Europe, the intrusive millet grain from context M8 at Gumelnița (Table 1) (2809 ± 60 BP; calibrated to 1125–818 cal BC, 2σ) fits comfortably into the chronological bandwidth defined for the transition between the 12th and 9th centuries BC, paralleling the Noua-Coslogeni group, generally placed in the 13th–11th centuries BC (Bolohan 2016), and aligning with the calibrated ranges characteristic of the Basarabi culture (multi-sites summative: 1300 cal BC to 830 cal BC) (Conrad and Krauss 2020), as well as with data of the pair group Babadag (most clustering between 1250–900 cal BC) (Ailincăi et al. 2017, 2022, 2024), and the contemporaneous ^{14}C determinations from the Early Iron Age in the Republic of Moldova (series from Saharna Mare), which cover interval of 1114–807 cal BC (Băț and Zanoci 2022). So, the calibrated interval of sample P207 securely places this intrusive find within the established Early Iron Age chronological horizon of the Balkans, aligning it with the wider regional transition from the late second to the early first millennium BC.

Nevertheless, the considerable distance between this settlement and the locus of discovery also suggests alternative possibilities: small-scale storage or agricultural activity by Basarabi communities along the terrace; the presence of as-yet undetected Early Iron Age features now obscured by recent afforestation; or the destruction of relevant deposits beneath the extensive footprint of the former agricultural combine at Ulmeni (Figs. S1 and S10). Within this interpretative landscape, the intrusive grain recovered from M8 (P207) serves as an eco-chronological proxy, preserving otherwise inaccessible evidence for the earliest Iron Age horizon in the vicinity of Gumelnița and providing a crucial temporal anchor for a segment of the local prehistoric sequence that is archaeologically underrepresented.

This highlights how modern disturbances can erase whole segments of archaeological strata, while intrusive ecofacts may preserve otherwise inaccessible information. In multi-stratified and/or multi-period sites like Gumelnița, such intrusive materials become critical indicators for reconstructing poorly investigated time periods, refining spatial models of settlement organisation, and improving our understanding of past land-use systems.

4.2. Millet cultivation at Gumelnița site

Recent experiments on the effects of manuring on millet isotopic values by Christensen et al. (2022) demonstrated that broomcorn millet grown on manured soils exhibits markedly higher $\delta^{15}\text{N}$ values (mean 5.8‰) compared with plants cultivated on unmanured soils (mean 0.3‰). Yang et al. (2024) proposed interpretative thresholds of approximately 1‰ for low organic input and 4‰ for high input. When the values obtained in this study are evaluated against these benchmarks—and against the thresholds established for C_3 plants by Fraser et al. (2011)—the $\delta^{15}\text{N}$ result for sample GUM-122 from the Gumelnița site (Fig. 2b) suggests cultivation under moderate levels of manuring. In contrast, isotopic evidence from C_3 plants at the site indicates medium to high levels of organic input, likely resulting from the seasonal flooding of the Danube River. This pattern suggests that Chalcolithic crops were cultivated within the floodplain, where naturally nutrient-enriched and well-watered conditions prevailed. This interpretation is supported by the isotopic similarities between wild and domestic taxa, the elevated $\delta^{15}\text{N}$ values, and the higher $\Delta^{13}\text{C}$ values observed in the cultivated cereals (García-Vázquez et al. 2023).

A further consideration is that millet is a summer crop, coinciding with the period when the Danube River typically floods (see Fig. 1b from García-Vázquez et al. (2024)). Consequently, millet cultivation would have

taken place outside the flooded zones, most likely on the adjacent river terrace. Such areas, lacking direct nutrient input from flooding, would require manuring to sustain productivity. The $\delta^{15}\text{N}$ values from GUM-122—lower than those of the contemporary C3 plants—indicate moderate manuring, supporting the hypothesis that millet was grown on the terrace rather than within the floodplain. However, without collagen isotopic data from contemporaneous humans and domestic animals, it remains difficult to determine whether the millet was cultivated primarily for human consumption or as animal fodder.

Isotopic studies on the diet of Bronze Age inhabitants from Romania are scarce. The only study focuses on two sites from the Monteoru culture (Middle Bronze Age), dated to 2280–1500 cal BC (Agurauja et al. 2018). Notably, millet remains were absent from these sites, and isotopic data from both humans and animals indicate no evidence of C4 plant protein consumption. The absence of millet in both archaeobotanical records and stable isotope studies associated with the Monteoru culture supports the hypothesis of a large-scale introduction of millet into Europe—and specifically into Romania—after 1500 cal BC. Both our new data from Gumelnița and other radiocarbon dates from Romania (Figs. 2a and S8) postdate this threshold.

From ca. 1500 BC, a clear C4 isotopic signal becomes visible in human remains from sites in Poland and north-western Ukraine (Pospieszny et al. 2021). During this period, millet was also incorporated into human diets in Italy (Varalli et al. 2022). Taken together, these data indicate that millet expanded rapidly westwards from the North Pontic steppes across Europe, reaching the Iberian Peninsula by at least the thirteenth century BC (Alonso and Pérez-Jordà 2023; González-Rabanal et al. 2022).

5. Conclusions

The results presented here demonstrate that intrusive archaeobotanical ecofacts—typically dismissed as “contaminants” that obscure rather than clarify archaeological interpretation—can, under certain methodological conditions, become analytically indispensable. At multi-stratified and multi-period sites such as Gumelnița (Romania), intrusive plant macroremains, dated independently of their depositional context, provide a rare opportunity to recover traces of occupational phases that have been rendered archaeologically invisible by complex post-depositional dynamics. By combining direct ^{14}C dating, stable isotope analysis, and high-resolution stratigraphic documentation, we show that the millet grains recovered from Chalcolithic funerary contexts are neither noise nor error: they are proxy indicators of anthropogenic activity belonging to a later Bronze Age / earlier Iron Age horizon, largely erased by decades of diverse anthropogenic and natural processes (e.g., mechanical disturbance, sediment displacement, landscape modification).

This approach offers a methodological and theoretical recalibration of how archaeologists conceptualise intrusion. Rather than treating intrusive ecofacts as interpretative failures—evidence to be discarded—they can be reframed as archaeological signals displaced by formation processes but still epistemically valid.

In this case, the intrusive grains constitute the only surviving direct evidence for millet cultivation in the Gumelnița micro-region during the later 2nd millennium BC and early 1st millennium BC. The new radiocarbon results presented here substantially strengthen the absolute chronological framework of the Balkans and southeastern Europe. These dates replace the previous Gumelnița “archaeological point” on regional ^{14}C maps, which had been inferred solely from diagnostic Bronze Age and Early Iron Age artefacts

(ceramics, metal objects, and associated typological criteria) whose chronological ranges remained broad and dependent on relative sequencing. By providing securely dated, species-specific botanical markers, our results anchor the Gumelnița area within the absolute temporal horizon of later 2nd- and early 1st-millennium BC developments, thereby correcting and refining a long-standing lacuna in the regional radiocarbon landscape. Their contribution is disproportionate to their number: they offer the first chronometrically grounded confirmation of later prehistoric activity in a zone previously documented only through artefactual evidence, thus integrating the site more firmly into supra-regional chronological and cultural reconstructions.

Moreover, their isotopic signatures refine our understanding of land-use strategies, suggesting cultivation outside the Danube floodplain, likely on elevated terrace zones requiring moderate manure inputs. These data contribute to broader debates on the tempo and mode of millet dispersal across Europe and highlight the methodological potential of integrating displaced ecofacts into regional palaeoeconomic models.

More broadly, this study emphasises that site formation theory, archaeobotany, and isotopic science must be jointly mobilised to reveal otherwise inaccessible past behaviours. The Gumelnița case illustrates how modern disturbances, institutional archives, the legacy of early excavations, and taphonomic complexity can selectively obliterate entire archaeological phases, while still allowing fragments of those lost horizons to persist as redistributed botanical proxies. Recognising and harnessing such redistributed signals requires a theoretical shift: intrusive materials do not simply intrude—they often bear witness, preserving evidence for cultural sequences insufficiently documented by traditional artefactual or stratigraphic means.

Finally, the implications extend beyond the specific case study. In regions where settlement palimpsests, agricultural landforms, and post-1950s mechanisation have reshaped archaeological landscapes, intrusive ecofacts may constitute a systematic and underexploited line of evidence for reconstructing past human activity. Their correct identification, direct dating, and isotopic investigation can significantly strengthen chronological models, illuminate minor or short-lived occupations, and refine reconstructions of past ecosystems and subsistence strategies. In this sense, the ability to recognise meaning in displaced materials becomes a methodological asset—rather than a liability—for archaeological inference.

Declarations

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Author Contribution

Ana García-Vázquez and Cătălin Lazăr conceived and designed the study. Mihaela Golea conducted the archaeobotanical analysis. Gabriela Sava and Tiberiu Sava performed the sample pretreatment and AMS radiocarbon dating. Ana García-Vázquez carried out the isotopic analyses. The first draft of the manuscript was prepared by Ana García-Vázquez and Cătălin Lazăr, and all authors contributed to subsequent revisions. All authors read and approved the final manuscript.

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Availability of Data

All data generated or analysed during this study are included in this published article and its supplementary information files.

Conflict of Interest

The authors declare no competing interests.

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Figures

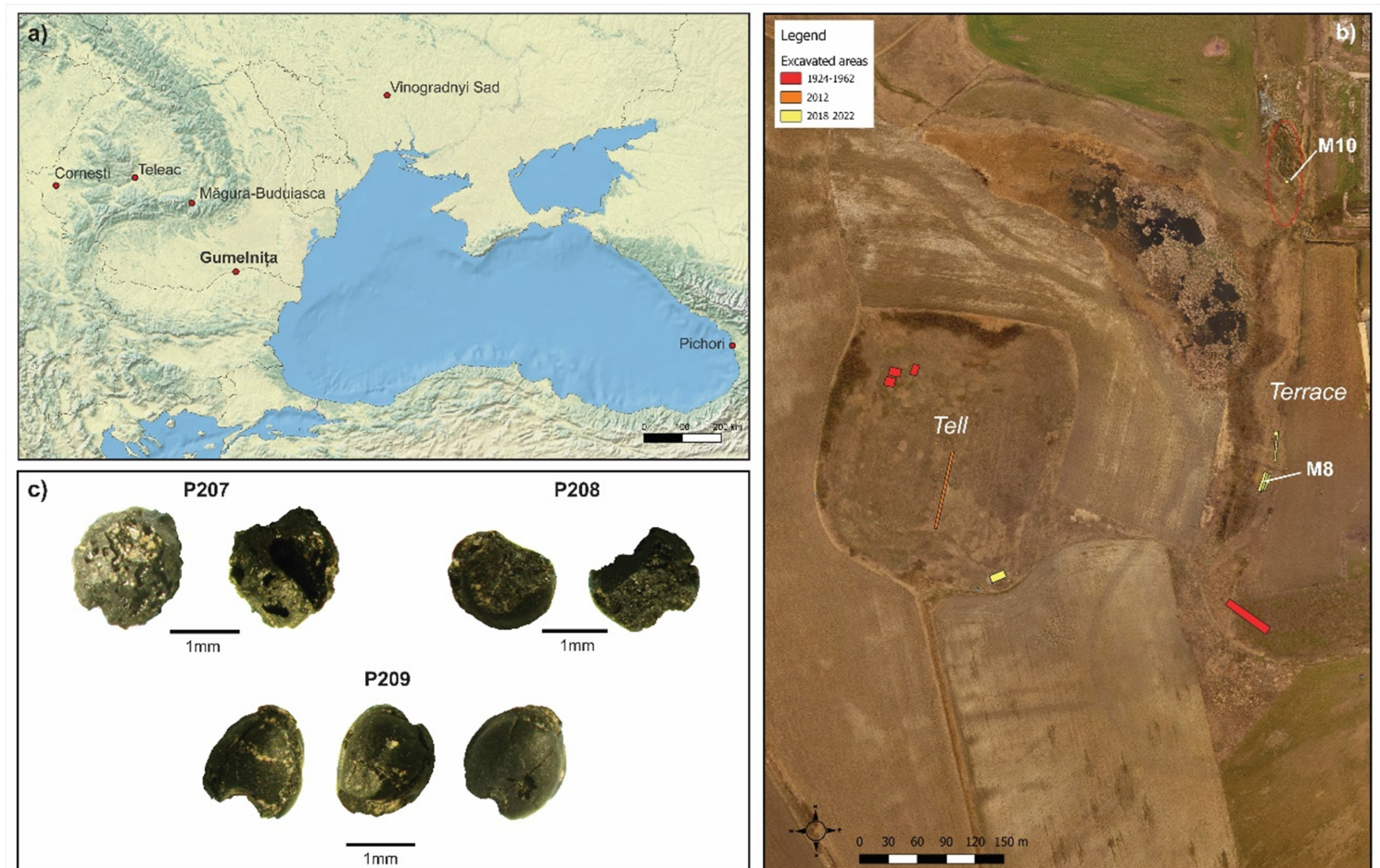


Figure 1

a) Location of the Gumelnița site and other sites mentioned in the text. b) Aerial picture of Gumelnița site showing excavation areas and the location of graves M8 and M10 from which the millet grains were

recovered. c) Charred millet remains: P207 (DET 60), broomcorn millet grain in dorsal and ventral views; P208 (DET 78), foxtail millet embryo shown from two angles; P209 (DET 80), broomcorn millet grain in dorsal, lateral, and ventral views

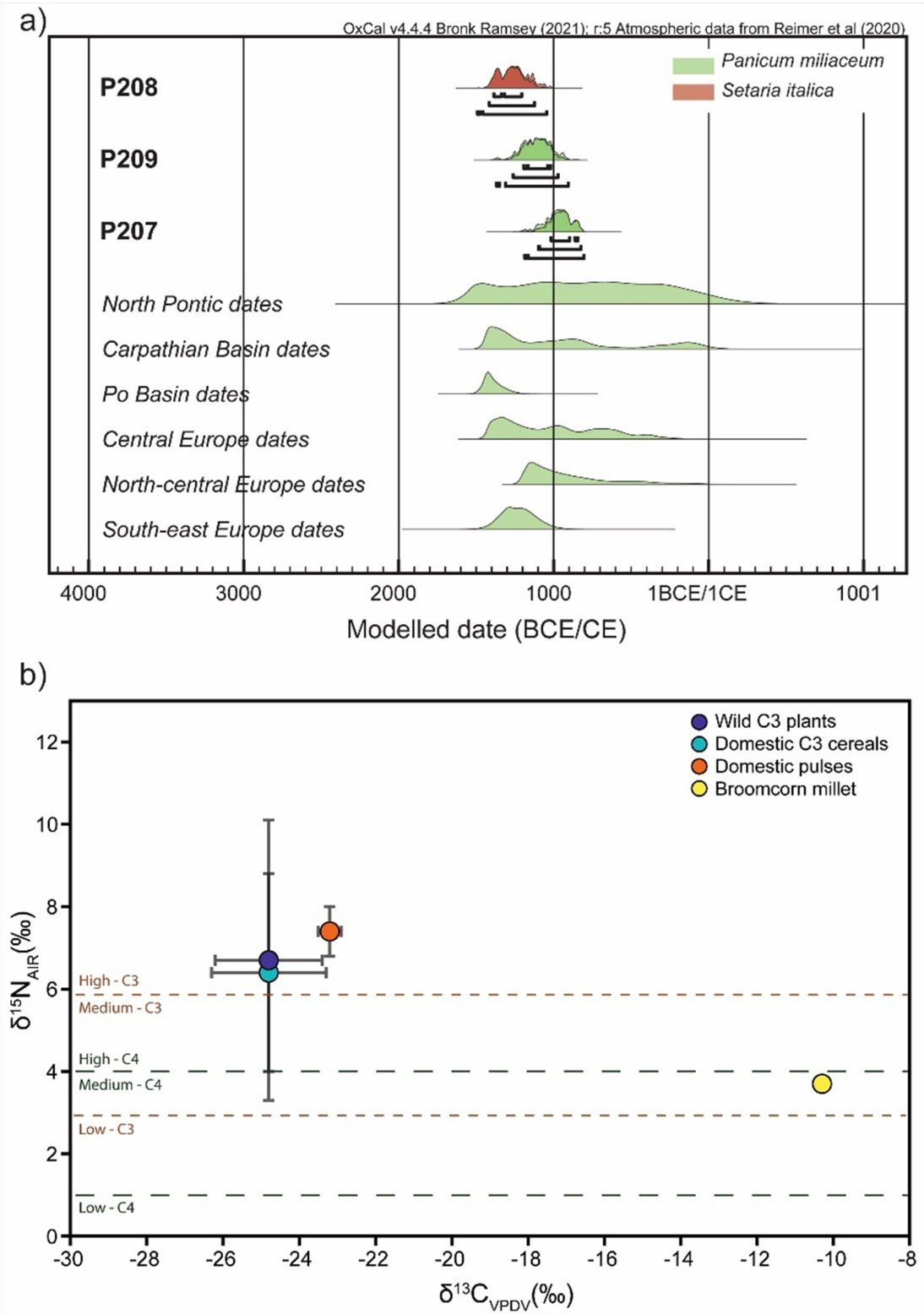


Figure 2

a) Broomcorn and foxtail millet grains from Gumelnița (samples P207–P209), alongside the model for the arrival of broomcorn millet in Europe adapted from Filipović et al. (2020). b) Isotopic results from the Gumelnița site C3 plants (Chalcolithic chronology) from García-Vázquez et al. (2023) compared with the broomcorn millet grain analysed in the present study. The dashed lines indicate the threshold of the different levels of manuring for millet following Yang et al. (2024) (black) and for C3 plants following Fraser et al. (2011) (brown).

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