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评 述
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显微CT技术助力植物考古与农业起源演化研究

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摘要 植物印痕是植物考古的重要研究对象之一, 往往存在于陶片、红烧土以及泥质塑像等泥土类遗存之中, 由植物嵌入泥土中后经燃烧而形成, 能够重现植物遗存在"新鲜"状态下的形态, 为探讨农业起源、作物驯化、自然环境和生业结构复原以及植物资源多样化利用等议题提供植物遗存信息, 具有重要的研究价值. 我国遗址出土的陶片、红烧土等遗存极为丰富, 其中蕴含的植物印痕信息亟待"发掘". 近年来, 基于显微计算机断层摄影(micro computed tomography, microCT)技术的印痕研究成为该领域的热点, 国际上已有相关研究对东南亚、东亚、非洲等地出土陶器中的植物印痕进行扫描分析, 探讨生业经济及作物驯化状况, 构建当地农业的时空发展框架, 彰显出该方法在国内植物考古和农业起源演化议题中有着广阔的应用前景.

关键词 植物考古, 植物印痕, 显微计算机断层摄影, 农业起源

农业起源是人类发展史上的重要转折点之一, 也是国内外考古学界所关注的热点问题之一. 植物考古研究极大地丰富了研究者所能够获取的植物遗存信息, 大植物与微体植物遗存鉴定在农业起源等议题的研究中已经取得了重大突破[1], 丰富了对以粟、黍和水稻为代表的早期驯化作物的发现、鉴定相关方法论[2~7]; 在明确早期农业起源时间、空间变化过程方面也取得较为显著的进展[8~12]; 并且在建立年代准确的气候变化与农业起源、人类活动的关系等方面产出了较多成果[10,13~16]. 但与此同时, 植物考古工作中时常面临浮选效果不理想, 大植物遗存发现数量较少或保存状况不佳等问题, 而微体植物遗存在种属鉴定等方面尚有待进一步的探讨空间, 农业起源研究仍然留有一系列问题尚厘清.

实际上, 植物在各类载体上留下的印痕同样值得关注, 这些印痕包含了大量的植物遗存信息, 在探讨农业起源等议题时起到不容忽视的作用. 本质上讲, 植物印痕承载着大植物遗存的表层形态信息. 植物印痕的形成过程并不复杂, 古人时常有意或无意地将植物种子、茎秆、叶片等按压或掺杂在湿润的泥土之中, 相对干燥的种子颗粒会从潮湿陶土中吸收一定的水分, 在这个动态过程中, 植物种子周围会沉积一层细密的土颗粒, 这层"土膜"通常能再现种子表面的微小形态细节[17,18]. 当泥土经过高温烧烤之后, 植物本体被炭化或完全破坏, 但再现其形态细节的印痕则会保留下来, 并且定格在被破坏前的时刻, 这种印痕的形态和大小

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与饱水状态下的植物相近，但经过高温后，实际上又会比饱水状态缩小约5%~8%[17,19]. 这种印痕往往出现在陶器、红烧土以及泥质塑像等物体的表面或内部.

植物印痕具有较高的学术研究价值. 首先，在植物遗存较少或保存情况差的地区，存在于陶器、烧土中的印痕能够填补当地植物遗存信息的空白，为探究遗址生态环境及其生业模式起到帮助. 在出土有植物遗存的地区，印痕材料也能够提供新的视角和丰富的信息，帮助研究者更加全面地看待问题. 其次，由于印痕展现的是植物被破坏前相对新鲜的形态，与炭化大植物遗存相比，其形态信息更加完整丰富. 此外，植物印痕所依附的陶器、烧土或塑像等载体使得印痕往往具有相对年代、文化特征等信息用于参考. 加之陶片、红烧土等相关遗存在我国的考古发掘现场或库房中几乎俯仰皆是，有待研究的植物印痕不在少数，是一笔庞大且亟待开发的珍贵“财富”.

国内外学者运用植物印痕材料已开展过一系列的考古学研究. 首先，在作物驯化与农业起源方面，研究者对遗址中的植物印痕进行鉴定和统计，往往通过形态学研究和历时性统计来定性、定量分析作物的驯化情况，以探究农业起源、发展及传播过程[20~24]. 其次，在生业信息与环境复原方面，研究者通过鉴定遗址出土的不同年代陶片中丰富的植物印痕，构建出该遗址不同时期生业经济结构的变化情况[25]. 另有一些研究对建筑烧土材料上树叶、枝条印痕进行了观察鉴定，尝试复原聚落所处的自然环境[26]，通常根据印痕所反映的植被组成来分析人类的季节性营造策略[27]. 此外，在考察具体的植物资源利用行为时，研究者可以基于植物印痕的构成(稃壳或者颖果)、保存状态(破碎或完整)以及依附载体所处的考古语境等信息探究古人的多种植物利用行为，如脱粒加工[28,29]、储藏[30]以及夹炭陶的制作工艺等[31].

近年来，以植物印痕为主要研究对象，围绕其展开的提取、观察、分析等相关工作的方法主要有两种(图1)：一种是以翻模为核心的方法，研究者利用橡皮泥、乳胶或硅胶(silicone)注入暴露在外印痕中，形成印痕的模型(cast)，继而再使用显微镜进行观察. 该方法无需严苛的实验环境和大型精密设备，具有便捷性强、成本低的优点，但只能获取暴露在陶片表面的少量印痕，且整体提取效率较低. 另一种为借助显微计算机断层摄影(micro computed tomography, microCT, 下文简称显微CT)技术对印痕进行数字化提取，该方法通过CT扫描形成印痕的数字三维图像，所提取的印痕在数量和形态上都更加全面、完整，同时，经数字化后的印痕图像更方便保存或传输.

本文介绍国内外植物印痕研究史和显微CT技术在印痕研究领域的应用.

1 植物印痕研究简史

在浮选法出现之前，考古发掘出土的植物遗存数量较少，而植物印痕往往存在于陶片、泥质塑像和红烧土中，便于研究者利用已入藏的文物开展研究，这使得考古学家在100多年前就开始关注植物印痕，这种持续的关注促进了印痕研究方法论的发展和完善. 在19世纪末，一些学者对欧洲多个新石器至青铜时代遗址出土陶片上的印痕进行了种属鉴定[34~36]，认为是大麦(*Hordeum* sp.)和小麦(*Triticum* sp.). 其他地区的考古学者对印痕材料的关注则稍晚，日本学者Yamanouchi[37]于1925年对日本弥生时代陶器上的水稻印痕进行了鉴定，提出可以使用黏土、石膏或熔点低的合金作为翻模材料. 美国学者Hendry[38]在20世纪30年代关注到墙体中的植物印痕，并尝试将相对完整的种子印痕分离出来.

在中国，对植物印痕的关注最早可追溯到1921年Andersson[39]发掘仰韶村遗址时对陶器中植物印痕的关注，这些印痕后经瑞典植物学家鉴定为水稻[40]，这一发现改变了Andersson[39]认为仰韶先民以小麦为主要作物的观点. 观察印痕一直是一种获取植物遗存信息的常见手段[41,42]，建国后，安志敏[43]、赵青芳[44]、丁颖[45]、黄宣佩[46]以及蒋缵初[47]等学者[48~51]对陶片或烧土中的水稻、粟以及植物茎秆印痕给予了密切的关注，以印痕为依据对遗址的生业状况以及建筑、制陶工艺进行了探讨. 有研究者依据显露在物体表面印痕的大致形状和纹理“顺手”做出种属判断，借此对遗址的生业经济进行讨论[45~48,50,52]；有研究者则尝试将留有部分植物残片的印痕分离出来，再进行鉴定分析[53~55]；或者不对植物本身深究，转而对陶器的制作工艺或建筑的营造技术等内容做出简单的分析[43,44,48,50,56]. 这类分析较为方便快捷，是一种获取植物信息的有效手段，但只限于对少量印痕的直接观察而不涉及提取工作，适用于较为扁平且大部分外露的体积较大的植物印痕，如水稻、大麦、小麦以及叶片等，同时，阴纹也不符合习惯的观察逻辑.

20世纪40年代，随着Jessen和Helbaek[57]对斯堪的

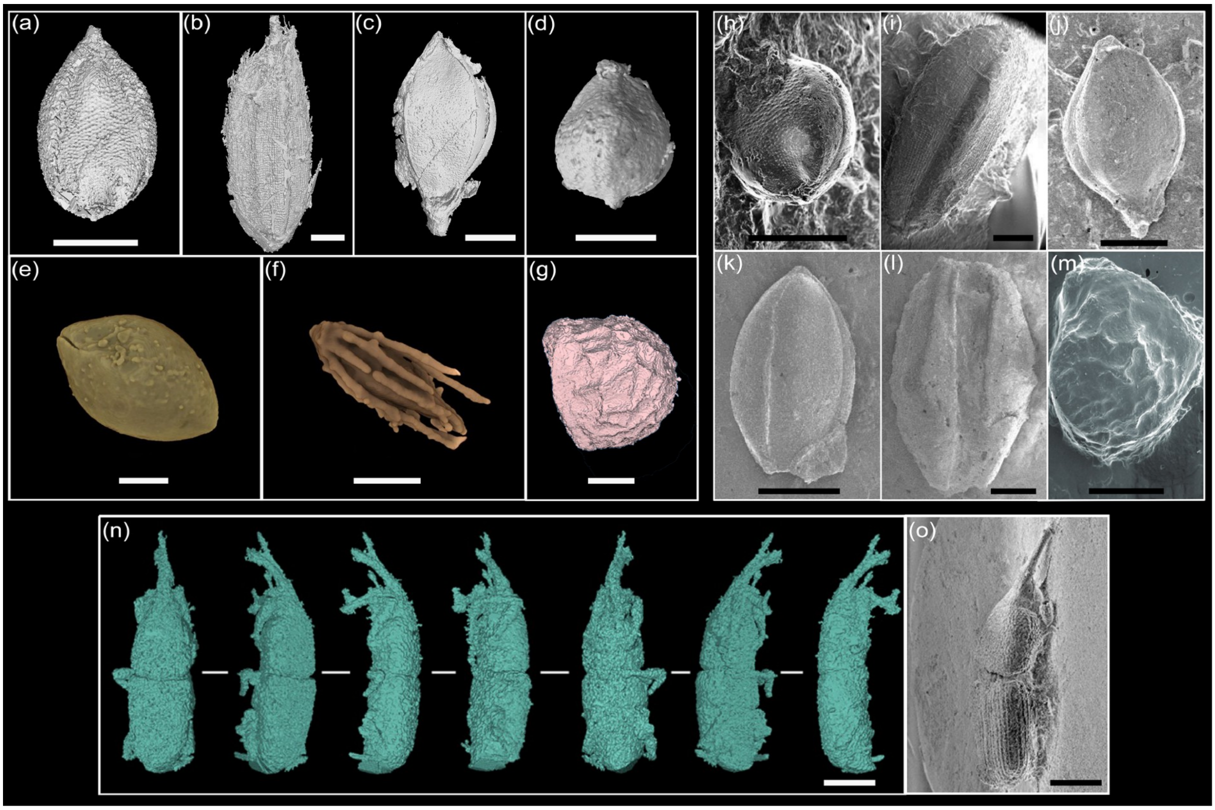

图 1 (网络版彩色)采用显微CT与硅胶翻模方法提取的各类植物及昆虫印痕图像. (a)~(g) 植物印痕的CT图像; (h)~(m) 植物印痕的硅胶模型的扫描电子显微镜(scanning electron microscope, SEM)图像. (a) 粟; (b) 水稻; (c) 稗; (d) 萤蔺; (e) 高粱[22]; (f) 珍珠粟[21]; (g) 椿叶花椒[32]; (h) 粟[33]; (i) 水稻[33]; (j) 稗; (k) 黍; (l) 大麦; (m) 椿叶花椒[32]; (n) 玉米象虫的CT图像[30]; (o) 玉米象虫的硅胶模型的SEM图像. (a) 提取自河南双槐树遗址, 图片来自作者; (b)~(d) 提取自浙江上山遗址, 图片来自作者. (j), (k), (l), (o) 来自日本熊本大学小畑弘己教授实验室网站(http://www.fhss.kumamoto-u.ac.jp/archaeology/kokuzo/kinds/index.html). 比例尺: 1 mm

Figure 1 (Color online) Images of various plant and insect impressions obtained by microCT and silicone compound casting methods. (a)−(g) CT images of various plant impressions; (h)–(m) SEM images of silicone casts of various plant impressions. (a) *Setaria italica*; (b) *Oryza sativa*; (c) *Echinochloa* sp.; (d) *Scirpus juncoides*; (e) *Sorghum bicolor*[22]; (f) *Pennisetum glaucum*[21]; (g) *Zanthoxylum ailanthoides*[32]; (h) *Setaria italica*[33]; (i) *Oryza sativa*[33]; (j) *Echinochloa* sp.; (k) *Panicum miliaceum*; (l) *Hordeum vulgare*; (m) *Zanthoxylum ailanthoides*[32]; (n) CT image of *Sitophilus zeamais* impression[30]; (o) SEM image of silicone cast of *Sitophilus zeamais* impression. (a) is from the Shuanghuaishu site in Henan provided by the author; (b)−(d) are from the Shangshan site in Zhejiang provided by the author. (j), (k), (l), (o) Images are from the laboratory website of Professor Obata Hiroki from Kumamoto University in Japan (http://www.fhss.kumamoto-u.ac.jp/archaeology/kokuzo/kinds/index.html). Scale bar: 1 mm

纳维亚和英国植物遗存研究工作的深入，植物印痕作为植物信息载体的可靠性得到认可. 文献[57]几乎不涉及具体的研究方法，但是零星地提到“橡皮泥(plastilina)”一词，对印痕的翻模提取工作已然开展. 20世纪70年代之后，一些研究开始在不同程度上介绍从陶器表面提取植物印痕的操作流程[17,58,59]，较为系统的印痕研究方法论开始应用于欧洲的考古工作之中，此时翻模的原材料主要是橡皮泥或乳胶，部分日本学者也在尝试利用其他材料提升翻模效果的可能性[60]. 但受制于翻模材料对细节的复刻能力，该方法在鉴定较小植物印痕时的准确性受到了争议.

以黍(*Panicum miliaceum*)的印痕鉴定为例. 学界在20世纪80年代就已经基本确立了区分黍与其他常见黍族植物的方法：主要是通过观察黍的尺寸大小、一端尖另一端相对钝的特殊形态[61]以及较为光滑的内外稃[62]来判断. 而在当时开展的印痕研究之中，受制于橡皮泥等材料的翻模效果，以及外部印痕的不完整性，即多数情况下印痕只是种子的一半甚至一小部分，研究者在鉴定工作中并不能很好地利用上述的鉴定标准，而主要是通过光学显微镜对种子大致形态和尺寸进行观察比对[63]. 事实上，这种方法并不准确，以乌克兰东部一处遗址中出土的黍的尺寸为例[64]，其宽度浮动在1.0~1.8 mm之间，长度则在1.2~2.2 mm之间不等，这种浮动空间导致研究者很难单独从大致形态和尺寸上将

黍与一些黍族植物区分开来，往往还需参考稃壳的表面纹饰以及颖果胚和种脐的形态，而这些信息一般不能被当时的翻模材料所捕捉. 近10年来, 部分学者对当年黍印痕鉴定工作提出了不同意见，并对前人的研究结论提出了质疑[65~67].

20世纪90年代，硅胶的应用大大提升了植物印痕模型的细节精度. 硅胶是一种高分子合成材料, 一些学者在总结印痕翻模材料时指出[68]: "与橡皮泥、乳胶等材料相比，硅胶具有易于加工、便于脱模、复制精度高和耐高温性良好的优点，而且这种材料在室温下的收缩和硫化可以忽略不计." 早在20世纪60年代，硅胶就被考古学家应用于翻模石刻碑文、楔形文字板、钱币以及带有浅浮雕或刻划装饰的陶瓷器等遗物[69,70]. 同一时期，植物学和古植物学家将该材料应用于植物叶片气孔及植物化石印痕的翻模[71,72]. 20世纪90年代至21世纪初，日本学者首次尝试使用硅胶对陶器上的植物印痕进行提取[73]，并改进了实验操作流程[74]. 得益于优化的实验步骤以及硅胶的良好翻模效果，提取效率以及模型细节精度都得到了较大程度的提升，同时，SEM在该领域的应用使得研究者能够观察到植物印痕表面极为微小的形态细节，这在很大程度上提升了微小印痕鉴定工作的准确度[73]. 但是由于翻模方法操作较为繁杂, 步骤流程较长, 且难以提取器物内部的印痕[29,75]，这种方法在植物考古学界的推广还较为有限.

2 基于显微CT技术的植物印痕研究

显微CT技术自20世纪80年代开始兴起，从基础的CT技术发展而来，因其成像精度更高，能达到微米级别的分辨率而得名为显微CT技术，也被称为微CT、微焦点CT或微型CT等[76,77]. 当X射线穿越一定厚度的物体时其强度会有所衰减，而衰减的程度与样品的密度呈线性关系，X射线CT主要依靠这一原理实现对物体的断层成像. 当X射线束穿透被检测对象，探测器测定从多个方向透过该物体的X射线强度, 使用数学方法求解出衰减系数在样品某截面上的分布矩阵并生成二维灰度分布图像，后将各个方向的投影经计算机重构转化为三维数字图像，从而实现对样品的三维成像[76,78,79]. 研究者可以利用配套软件结合自己的需求进一步对图像进行处理，可进行提取、解剖、删除、测定以及结构分析等一系列操作.

随着更多学者认识到显微CT技术的优点，该技术在考古学中的应用也愈发频繁，一些研究开始将大植物遗存材料作为显微CT分析的对象[80]. 这些研究使用显微CT扫描来将植物的形态特征可视化，包括种子形态特征[81,82]、果皮的组织层次[83,84]以及微观层次特征, 如维管束、纤维组织和细胞等[85,86]. 显微CT技术能够帮助研究者获取遗存的内部信息，为先前基于外部形态的鉴定标准提供补充. 这类研究涉及的核心内容大致可归为两种, 一是对植物遗存的种属进行鉴定, 包括鉴定木材[85~87]、地下根茎[81,88]以及水果类遗存等[83,84]; 二是对植物遗存的驯化状态进行鉴定评估，包括对水稻[89]、豆类植物[90,91]的驯化标准进行探索.

值得提及的是，在X光源的选择上，除常见的高能电子束轰击靶材产生X射线的光源外, 同步辐射光源也在一些植物考古学研究中得到应用[90,91]. 同步辐射是速度接近光速的带电粒子在磁场中沿弧形轨道运动时放出的电磁辐射，由于它最初是在同步加速器上观察到的, 便被称为"同步辐射". 同步辐射是具有从远红外到X光范围内的连续光谱，研究者利用X射线波段开展显微CT研究，该光源具有高强度、高亮度、高度准直以及高度极化等特性. 在合适的情况下, 基于同步辐射光源的显微CT研究能够获取更高信噪比、更高分辨率、更加清晰的图像[92~94].

近年来，显微CT技术开始应用到植物印痕研究中，这种方法将陶片、红烧土之类的载体作为扫描对象，借助显微CT设备直接观察到载体内部的全部印痕，并且能够构建出印痕的三维模型(图2)，该方法较翻模的印痕研究方法具备独特的优势(图3). 目前已发表的多项研究对东南亚、东亚、非洲等地出土陶器中的植物印痕进行了扫描分析，涉及遗址年代距今7500~800年不等(表1). 涉及的作物包括水稻[24,95,96]、粟[96]、珍珠粟[21]、紫苏属(*Perilla* ssp.)[96]、高粱[22]以及椿叶花椒[32]等, 还包括玉米象虫等昆虫印痕[30].

在探讨农业起源、作物驯化以及生业经济方面，多项研究已通过观察水稻小穗轴印痕对东亚及东南亚地区的水稻驯化情况进行了分析，尝试评估特定时空框架下稻作农业的驯化与传播情况. 2017年发表的一项研究对越南南部遗址出土的陶片进行了扫描[24]，提取并鉴定了数十枚水稻小穗轴印痕，并认为皆为驯化型，该研究补充了因大植物遗存缺失而造成的当地水稻驯化研究的空白. 2020年, 研究者对马来西亚婆罗洲地区槟榔洞遗址出土的陶片进行了扫描[95]，发现了带有驯化特征的水稻小穗轴有39枚，占比为78%，为探讨

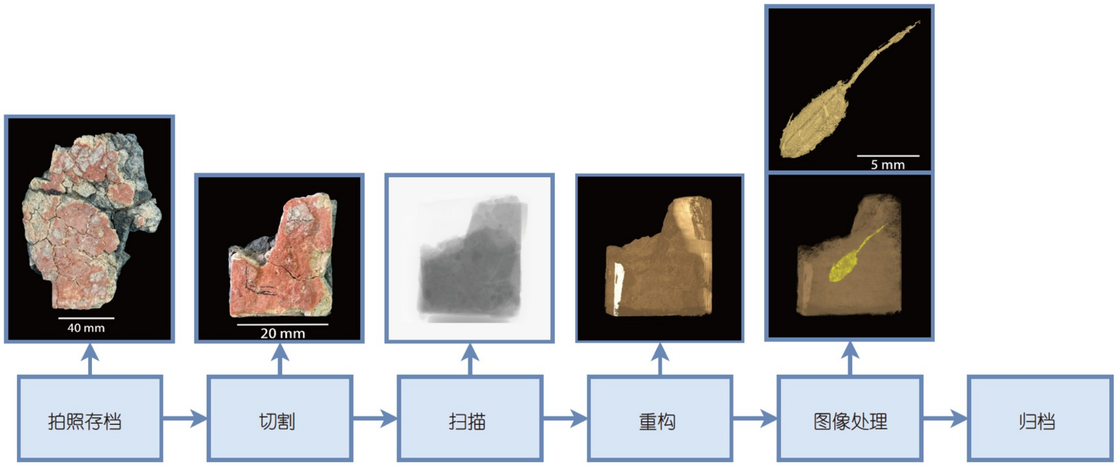

图 2 (网络版彩色)显微CT扫描印痕流程图. 以上山遗址陶片为例
Figure 2 (Color online) MicroCT scanning workflow for impression. Exemplified with pottery sherds from the Shangshan site

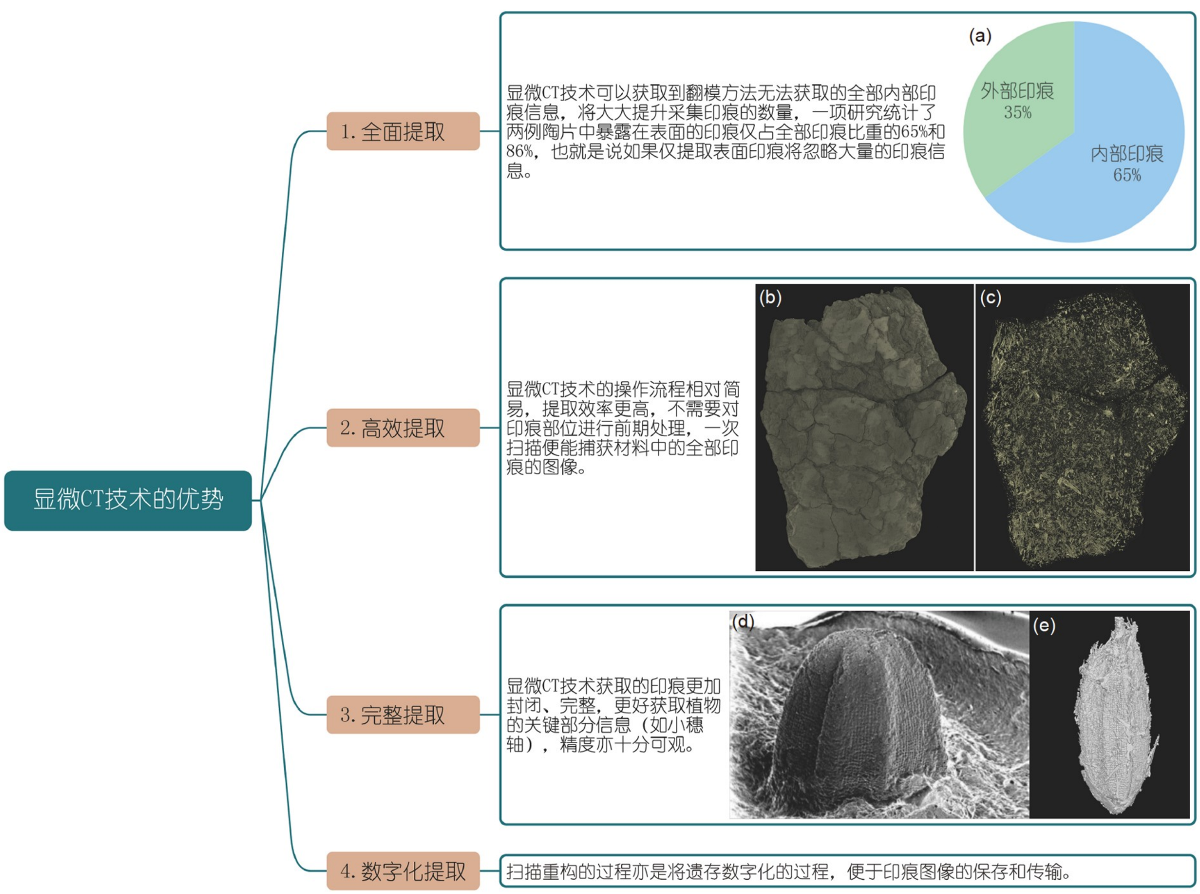

图 3 (网络版彩色)显微CT技术的优势. (a) 一例陶片中内、外印痕所占比重[30]; (b) 上山陶片CT图像; (c) 上山陶片内部印痕分布示意图; (d) 外部水稻印痕硅胶模型的SEM图像[33]; (e) 内部水稻印痕的CT图像
Figure 3 (Color online) Advantages of microCT technology. (a) Proportions of inner and outer impressions in a ceramic sherd[30]; (b) CT image of a Shangshan pottery sherd; (c) schematic distribution of inner impressions in the Shangshan pottery sherd; (d) SEM image of silicone cast of external rice impression[33]; (e) CT image of internal rice impression

表 1 世界范围内已开展显微CT印痕研究的考古遗址

Table 1 The archaeological sites where impression studies based on microCT have been conducted worldwide

遗址名称	遗址年代	涉及印痕种类	所在国家
AZ22[21]	7500–6950 cal a BP	珍珠粟	马里
MT25[21]	6240–5090 cal a BP	珍珠粟	马里
MK36[21]	5020–3940 cal a BP	珍珠粟	马里
海什姆吉尔拜23遗址[22]	ca. 5700–4900 a BP	高粱	苏丹
安山遗址[24,97]	ca. 4200–3150 cal a BP	水稻	越南
禄江遗址[24,97]	4000–3300 cal a BP	水稻	越南
若涅遗址[24,97]	3555–3265 cal a BP	水稻	越南
槟榔洞遗址[95]	1990–830 cal a BP	水稻	马来西亚
悦二遗址[96]	3190–2820 cal a BP	水稻、粟、紫苏	日本
役所田遗址[30]	3600 a BP	玉米象虫	日本

该地区水稻驯化进程提供了直接证据. 在非洲地区, 已有学者对该苏丹、马里等地的高粱[22]、珍珠粟[21]等黍族植物印痕开展了历时性的研究, 通过对小穗轴形态的观察来评估该类作物的驯化情况, 尝试构建了当地黍族作物的驯化序列. 此外, 日本学者对日本九州岛一处遗址出土的一万多片陶片进行了检查, 结合CT扫描和翻模方法共发现127枚印痕[96], 主要包括水稻、粟、紫苏属等植物, 并利用CT扫描定位内部印痕继而精准钻孔提取炭化物质进行测年. 该研究梳理了日本九州岛北部农业发展的时间框架, 将该地区的谷物种植生业模式发生时间定位在公元前10世纪下半叶至公元前9世纪上半叶之间.

值得一提的是, 日本学者在使用显微CT研究植物印痕的同时也关注了昆虫印痕, 昆虫遗存一般较难获取, 浮选所发现的昆虫往往不完整, 因为大部分情况下只有主要成分为甲壳质(chitin)的外骨骼才能在埋藏环境中保存下来[98], 并且存在混入的风险, 而昆虫的印痕往往更加清晰、完整并排除是混入物的可能. 2020年一项研究扫描发现, 日本绳文时代至弥生时代初期陶片内含有大量玉米象虫印痕(图1(n)), 研究认为, 这可能是陶工有意地将其掺入陶器中, 以希冀粮食丰产[30]. 昆虫印痕的研究为探究史前人地关系以及农业生产状态提供了新视角.

3 显微CT技术应用于印痕研究的前沿和展望

基于印痕材料本身的特性以及配套方法的诸多优点, 显微CT的印痕研究在探讨植物考古与农业起源相关前沿课题上具备广阔的应用前景.

首先, 在大植物遗存保存状态差的地区[99]以及地层信息薄弱的沙漠、戈壁、高原等地貌单元[100,101], 显微CT技术应用于印痕研究能为了解当地史前生业经济状况提供关键植物遗存信息, 补充农业起源关键阶段或农作物跨区域传播路径上的缺环. 同时, 由于印痕依附于陶片等黏土类材料, 可采用光释光、热释光等方法直接对其进行测年, 亦可从中提取植硅体、脂肪酸等材料测年, 这将为相关印痕提供较为可靠的绝对年代信息, 从而有望未来在农业起源与早期东西方文化交流与互动等议题上取得重大研究突破.

其次, 印痕承载信息丰富, 不受浮选孔径和炭化作用等因素的影响, 最大限度包含了陶器制作时所添加或混入其中的全部植物信息, 较完整地保存了芒、稃壳、小穗轴以及茎叶等多种植物部位, 并且复刻了新鲜状态下的植物, 呈现其清晰的形态细节. 种子以外的其他植物部分, 比如茎叶亦是重要的经济产品, 多项研究已证明其在人类生产和生活中占有极其重要的地位[102~104]. 未来待茎叶种属鉴定的方法论取得突破, 关于茎叶印痕的系统研究将极大拓展对古人利用植物方式的认知.

值得关注的是, 印痕中所保存的芒、穗轴等植物部位还将为作物驯化研究提供新视野. 小穗轴形态反映植物的落粒性情况, 被认为是研究水稻[105]、大麦[106]、小麦[107]、高粱[22]等农作物驯化进程时的重要指标之一. 相比之下, 由于粟黍穗轴很难从浮选中获取, 目前学界对粟黍这类重要旱作作物驯化状态的判断几乎仍以种子尺寸为单一标准[108]. 未来印痕研究方法在探寻粟黍穗轴遗存方面具有不可替代的优势, 有望在

粟黍驯化研究方面取得突破性进展. 芒上刚毛的特征亦被认为是水稻、小麦等作物驯化的重要指标之一[106], 芒很难从植物浮选中获取, 但可以相对完整地保存在植物印痕中. 对南方地区常见夹炭陶或草拌泥遗存中水稻相关印痕(芒、穗轴和稻谷等)的系统提取, 有望进一步验证和完善目前基于大植物遗存证据所建立的水稻驯化序列.

此外, 基于显微CT技术的印痕研究将植物遗存数字化, 功能丰富的CT处理软件使印痕研究具备高精度量化印痕及其所依附的考古样品尺寸、体积的能力, 在鉴定植物种属的同时, 亦可获取样品孔隙率、各类羼和料所占体积的比例关系等信息, 这在对史前夹炭陶掺合料工艺开展量化研究等方面亦具备较大潜力.

4 结语

本文阐述了植物印痕的基本概念、研究价值、研究历史, 并着重介绍了基于显微CT的研究方法及相关案例, 为未来相关技术方法在我国植物考古与农业起源演化研究上的应用提供参考.

植物印痕作为一类常见的遗存, 目前在我国植物考古实践中受到的关注还较为有限. 目前印痕研究已形成一套可供直接参考的相对成熟的研究方法, 加之陶片、红烧土等相关遗存在我国考古发掘现场或库房中几乎俯仰皆是, 有待研究的植物印痕应不在少数, 该领域具备广阔的应用前景.

基于显微CT的研究方法在印痕研究领域显示出十分广阔的前景, 较以往翻模的方法具备明显的优势(图3), 但目前尚未在植物考古领域得到广泛应用. 主要面临的问题可能有两点: 首先, 受制于大植物鉴定方法的瓶颈, 该方法仍局限于植物种子类印痕的鉴定和分析, 对茎秆等其他类型植物印痕的鉴定仍有一定的困难, 未来尚有待更多植物印痕模拟实验与印痕数据库积累; 其次, 该方法依托于大型工业设备, 扫描及分析成本都较高. 未来, 深度学习可能成为该领域所关注的热点, 鉴于深度学习已成为整个显微CT研究领域的热点话题, 目前已有学者探讨将识别和提取印痕的步骤自动化的可能性[80], 随着植物印痕数据库的不断扩充, 未来也许能够实现识别及提取的全自动化, 将大大提升研究效率, 使植物印痕研究的广泛推广更具可能性. 基于显微CT技术的植物印痕研究有望未来在农业起源和作物驯化与传播等议题的探讨上取得重大突破.

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Summary for “显微CT技术助力植物考古与农业起源演化研究”

MicroCT technology facilitating archaeobotany and the study of origin and evolution of agriculture

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The emergence of agriculture stands as a pivotal juncture in human history, garnering widespread interest within the field of archaeology. The identification of both macro and micro plant remains has marked considerable progress in studies pertaining to the origin and evolution of agriculture. Nevertheless, challenges persist, including suboptimal flotation results, limited or inadequately preserved macro plant remains, and the imperative for further exploration in identifying micro plant remains at the species level. Consequently, numerous questions in archaeobotanical research deserve further clarification. Indeed, equal emphasis should be placed on the examination of plant impressions, frequently unearthed within soil-related artifacts such as pottery shards, fired clay, and clay sculptures. These impressions faithfully replicate the morphology of plant remains in their “fresh” state, providing valuable insights into various aspects, including subsistence strategies, the diverse utilization of plant resources, the origin of agriculture, crop domestication, and the reconstruction of natural environments. In China, numerous deposits of unearthed artifacts containing significant information on plant impressions await exploration.

In recent years, there has been a notable shift in focus towards studies that leverage microCT (micro computed tomography) technology, emerging as a central component in the investigation of plant impressions. Previous research endeavors have applied scanning analyses to scrutinize plant impressions extracted from archaeological sites situated in Southeast Asia, East Asia, and Africa. These initial forays into impression studies utilizing the microCT approach have made significant contributions to the exploration of various issues in archaeobotany. As pioneering efforts, these studies underscored a substantial potential within the broader archaeological context.

The current study provides a comprehensive survey of the historical trajectory of plant impression studies and recent advancements in research utilizing microCT scanning technology. In particular, we outline potential breakthroughs expected to address specific scientific inquiries in the future, summarizing key areas of exploration across three aspects.

Firstly, in regions characterized by challenging preservation conditions for macro plant remains and limited stratigraphic information within geomorphic units, such as deserts, plateaus, and wastelands, microCT scanning of plant impressions within the field of view becomes invaluable in supplying crucial information on plant residues. This aids in understanding local subsistence strategies and fills gaps in cross-regional transmission paths of crops, promising substantial breakthroughs in research areas like early East-West cultural exchanges and interactions. Moreover, advancements in the methodology for identifying stem and leaf genera will significantly enhance our understanding of ancient human plant utilization practices through systematic examinations of stem and leaf imprints. It is noteworthy that certain plant parts, such as awns and rachises, which may be absent from flotation but well-preserved in impressions, offer a fresh perspective for investigating crop domestication. Additionally, microCT technology holds significant potential for quantitative research on prehistoric organic-tempered pottery. This opens up new avenues to explore ancient pottery technologies, providing insights into the quantitative aspects of prehistoric practices related to plant residues and additives.

This paper concludes by clarifying the current challenges and upcoming opportunities in microCT applications for the analysis of ancient plant remains. It emphasizes the substantial potential of artificial intelligence to make significant contribution to this field.

archaeobotany, plant impressions, microCT, origin of agriculture

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