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ORIGINAL PAPER

The application of 3D modeling and spatial analysis in the study of groundstones used in wild plants processing

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Abstract

In recent years, several works have proved the reliability of the application of 3D modeling and spatial analysis in the study of stone tool use. Monitoring surface morphometry resulting from the use of lithic tools has the potential to objectively quantify and identify patterns of modifications associated to specific activities and worked materials. In particular, the combination of surface morphometry with a systematic experimental framework and use wear analysis has the potential of foreseeing residue distribution areas over the groundstone surfaces, hence providing a key aid in establishing sampling strategies applied to archeological specimens. Here, we propose an approach that applies 3D modeling, performed through a close-range photogrammetry, and the use of GIS software to investigate surface modifications and residue distribution on groundstones used to process wild plants. Our work comprises a dedicated experimental framework in which modern tool replicas have been used to process different species of wild plant foods through grinding, crushing, and pounding. By applying 3D modeling and spatial analysis, we were able to characterize patterns of surface modifications related to each of the worked substances and activities performed. Moreover, we monitored the distribution of starch granules over the experimental groundstone surfaces and its variation in relation to the state of the worked substance and the action carried out. Our results provide one of the first experimental dataset focused on the use of groundstones for wild plant processing, and a reliable methodology for further studies related to the exploitation of stone technology and wild vegetal substances in the past.

Keywords 3D modeling · GIS · Groundstones · Experimental archeology · Residue analysis · Wild plants

Introduction

Functional studies, based upon use wear and residue analyses, provide essential information regarding ancient technology, as well as aspects concerning ancient human behavior and adaptive strategies. In most of the cases, functional interpretations rely on qualitative data, emerging from the microscopical identification of use wear patterns. In the last decade, numerous scholars have proposed various methods aimed to quantify use wear on knapped stone tools (Evans and Donahue 2008; González-Urquijo and Ibáñez-Estévez 2003; Ibáñez et al. 2014; Macdonald 2014; Stemp, 2001, 2014). Among those, the application of 3D scanning and Geographic Information System (henceforth GIS) in the field of use wear analysis has recently been discussed with regard to their potential for monitoring and quantifying use-related damage on macro lithic tools. For instance, GIS has been used to assess battering marks on both experimental and archeological pounding tools (Arroyo and de la Torre 2016; de la Torre et al. 2013). Specifically, de la Torre et al. (2013) were able, combining use wear results and GIS, to identify damage patterns associated with the exploitation of experimental quartz anvils to break bones, crack acorns, pound meat, and knap stones. Arroyo and de la Torre (2016), instead, combined use wear and GIS to investigate surface modification on archeological pounding tools coming from Beds I and II at Olduvai Gorge, providing relevant insights regarding the use of these implements in Early Stone Age contexts.

In the last few years, several works (Benito-Calvo et al. 2015; Caruana et al. 2014) tested the specific potential of the combination of 3D scanning and GIS in the quantification of battering

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marks on percussive tools. In particular, such methods were used by Benito-Calvo and colleagues (Benito-Calvo et al. 2015) in order to identify and compute the use-related damage on battered tools used by extent primates from Bossou (Guinea). As a result, the author highlighted the potentials of morphometric analysis in the discrimination between damage related to active and passive pounding activities. Caruana et al. (2014) presented the result derived from the use of a spatial recognition algorithm applied to 3D models of battered tools, finalized to identify variation in surface roughness on both experimental and archeological implements. By analyzing morphometric features as surface, volume, perimeter, and area, the authors were able to distinguish between natural and anthropogenic damage patterns. More recently, Benito-Calvo and colleagues (Benito-Calvo et al. 2017) investigated patterns of surface changes on experimental quartzite and basalt battering tools used to break bones. By treating 3D surface measurements obtained through the use of a confocal microscope and processed with GIS software, the authors were able to identify and monitor significant changes in surface topography at a micro scale. The results suggested differences in the degree of modification occurring between active and passive elements used to break bone, with the anvils exhibiting deeper modification while larger surface areas were modified on the hammerstones (Benito-Calvo et al. 2017) More recently, Benito-Calvo and colleagues (Benito-Calvo et al. 2018) evaluated the high potential of the application of 3D 360° morphometric analysis in the analysis of pounding tools. Through the direct processing of 3D point clouds, the authors analyzed various morphometric variables on a complete tool, measuring patterns of modification related to the use of stone tools in baobab fruit processing (*Adansonia digitate*) processing by Hazda foragers in Tanzania (Benito-Calvo et al. 2018). All of the aforementioned studies demonstrated how the application of quantitative approaches (e.g., GIS) in the analysis of stone tool use allows the identification of battered areas and the kinetics involved in the use of pounding tools. However, as already underlined by Arroyo and de la Torre (2016), a reliable interpretation of pounding tools function demands the qualitative data obtained though the microscopic analysis of the surfaces. To this matter, the study of Caricola and colleagues (2018) focused on the use of hammerstones coming from the Paleolithic site of Fumane Cave (Italy) represents a clear example of the combination of use wear analysis, 3D scanning and GIS. Indeed, the authors, through the application of this integrated approach, provided a detailed interpretation of the function and gestures associated with the use of macro tools at the site, stressing the importance of combining quantitative data coming from geomatic techniques with qualitative results achieved through use wear analysis performed at low and high magnifications (Caricola et al. 2018).

Despite the positive results achieved by combining 3D scanning and GIS techniques in the study of the use of pounding tools, the potential of such approach still needs to be fully tested with regard to the analysis of residue distribution. As a matter of fact, investigating spatial distribution of residues in relation to patterns of surface modification would allow one to better understand how activities and gestures in working these materials affect residue disposition on the used tools. As recently stressed by Mercader et al. (2018), by allowing to discern between naturally adhered organic remains (e.g., sediments) and use-related ones, patterns of residue distribution over a tool's surface positively contributes to the debate regarding ancient contamination,

Here, we present experimental data coming from the analysis of an assemblage of modern groundstones systematically utilized to process wild grain grasses, roots, and fruits. Our methodological approach focuses on the combination of 3D scanning performed through close range photogrammetry, spatial analysis, use wear, and micro-residue (namely starch granules) analysis. Such newly combined approach provides the first opportunity to investigate and quantify functional modifications associated with wild plant processing on experimental groundstone surfaces. Further, the analysis of the spatial distribution of residues allowed us to monitor how this relate to the performed gestures and to identify high potential residue sampling areas over a tool's surfaces. This latter aspect represents a new contribution to the analysis of ancient residues on stone tools with high potential to oversee sampling strategies of archeological groundstone. For this reason, even though we focused our analysis on wild plant processing, our results highlight the potential application of this methodological framework in future works focusing on groundstones used in domestic plant processing. In a broader perspective, our work aims to contribute to the ongoing debate in the field of starch research regarding ancient contamination and authentication of starch granules (Crowther et al. 2014; Mercader et al. 2018), providing new means for strengthening the validity of this analysis in the study of ancient human behaviors.

Methodology

In order to analyze patterns of modifications caused by the use of groundstones for wild plant food processing activities, we elaborated an integrated approach based on the combination of the following: (a) 3D scanning through close range photogrammetry; (b) utilization of a GIS software to investigate patterns of surface modification and distribution of both use wear and starch granules; (c) use wear analysis performed at low and high magnifications; (d) residue analysis; (e) experimental archeology (Fig. 1). Our combined approach allowed us to:

- gather quantitative and qualitative data related to wild plant processing using groundstones;

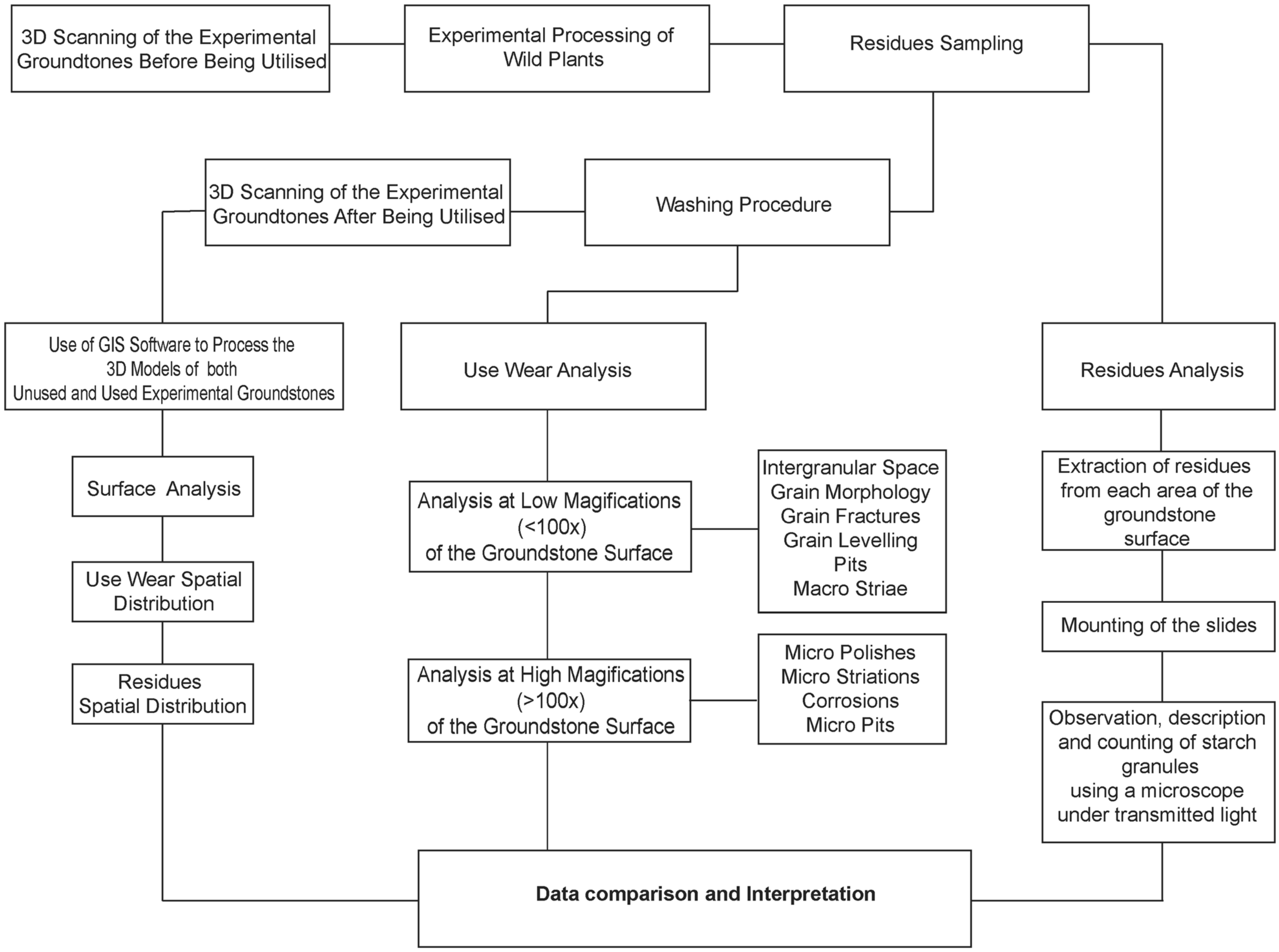

Fig. 1 Flowchart representing the workflow adopted to analyze each of the experimental groundstones

- perform a cross-comparison between the geomatic observations and the direct analysis of the utilized areas of the groundstones at low and high magnifications; and
- map residue distribution patterns across the tool's surface and investigate how they relate to the activity performed (gesture and worked material) and surface topography.

Experimental activity

The experimental activity, performed by MLC, part of a large-scale project (HIDDEN FOODS - ERC StG Project, GA 639286, PI: EC) focused on the exploitation of wild plants by Paleolithic and Mesolithic communities, was aimed to test the functionality of groundstones for processing different parts of wild plant foods, such as grains, roots, and fruits. Plant foods have been processed using grinding stone tools performing both pounding and grinding activities. Pounding involves the contact between the active and passive tools through a series of fast and repeated vertical movements, while during grinding the active tool is in continuous contact with the surface of the passive tool through back and forth, circular, or oblique movements (Adams 2014a; de Beaune 2004; Wright 1992). In terms of results, pounding is aimed to break into small pieces the processed substance, while grinding leads to the pulverization the worked matter (Adams 2014b). Some of the variables recorded included the following: (a) the type of wild plant worked; (b) the state (dry or fresh) of the worked material; (c) the gestures used during the test; and (d) the duration of the experiments. All the experimental groundstones presented in this study are made of very compact and homogeneous sandstones recovered from the Esaro River in South Italy (Fig. 2) (Tables 1 and 2). The mineral composition of the selected sandstone is characterized by a high presence of quartz (65%) and in lower percentages by pheldspar, muscovite, biotite, and chlorite, cemented within each other through silica, carbonates, and iron oxides. Overall, the size of the quartz grains is small (ca. 0.25 mm), is characterized by a high degree of angularity, and appears densely distributed within the matrix. The overall high homogeneity of the selected raw material allowed us to limit the variables affecting the development of use wear. Moreover, the material's high abrasive

Fig. 2 Experimental groundstones used for processing **a**, **b** *Rumex crispus* fruits, **c**, **d** *Rumex crispus* roots, **e**, **f** *Quercus pubescens*, **g**, **h** *Setaria italica*, and **i**, **l** *Avena sterilis*

qualities made it distinctly functional in particular during grinding activities. Regarding the species of plants processed, acorns (*Quercus pubescens*), oats (*Avena sterilis*), curly dock (*Rumex crispus*), and foxtail millets (*Setaria italica*) have been selected for our experiments due two main reasons. First, the selection of these specific plant species is given in light of the aims of the