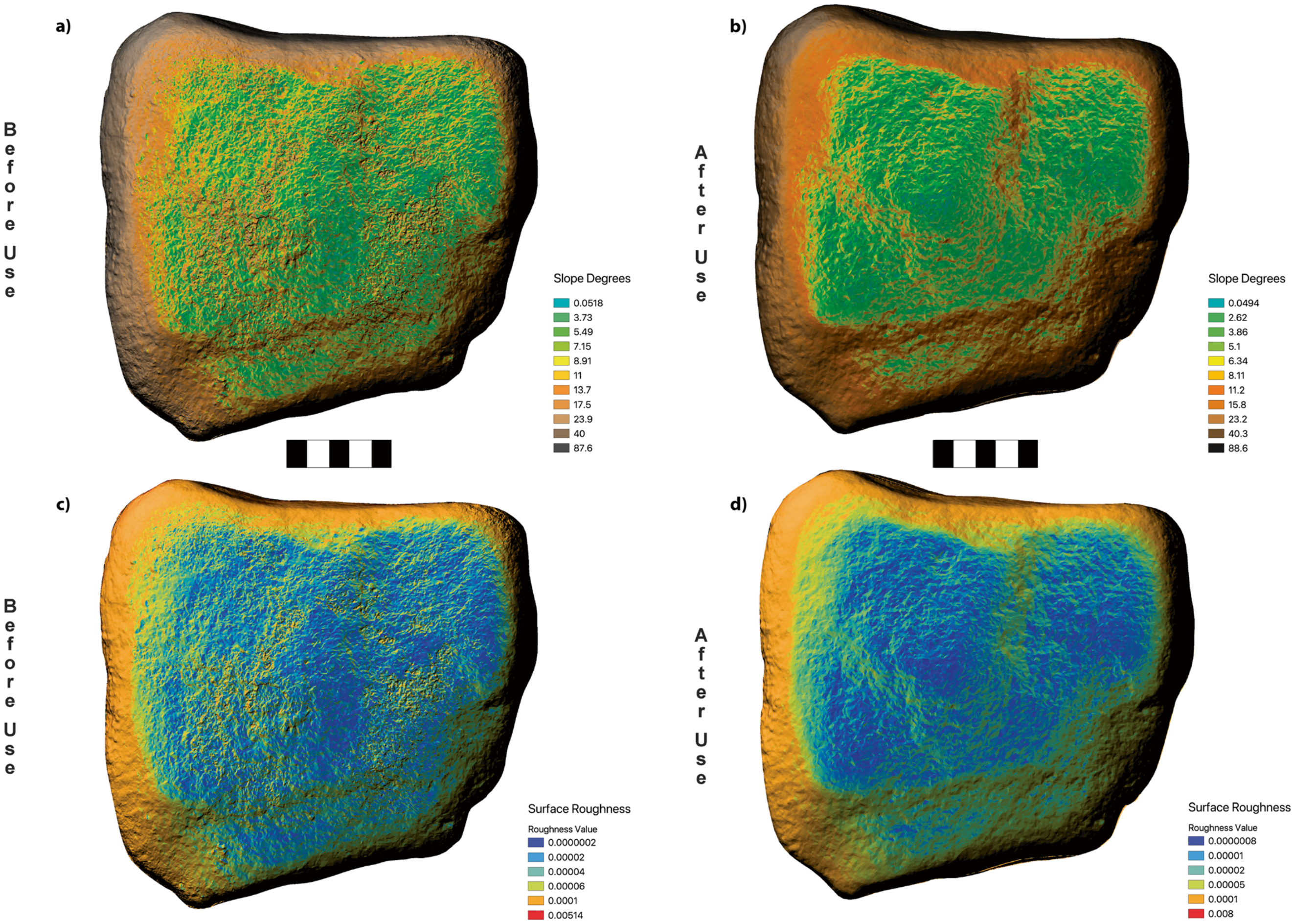

Fig. 10 DSMs representing the slope and surface roughness recorded before and after the use the groundstone

of the groundstone surface. Given the high number of identified starches, it was possible to highlight differences in the spatial distribution of intact, damaged specimens and lumps, over the tool's surface. Intact starches (n. 1787) were well spread across most of the groundstone surface (Fig. 12a, b). However, their maximum concentration was located over its lower right portion (square 6), the only area of the tool not directly involved in the grinding activity.

Concentrations of lumps (n. 252) and damaged starches (n. 524), instead, share the same localization over the lower central portion of the surface (square 5) while they are rare over the most utilized areas (squares 2, 3, and 4) (Fig. 12c, d). Single starches and lumps are very rare over the left corner of the groundstone (square 1). Such a paucity of granules may be related to the fact that this portion of the surface was utilized as a sort of prehensive area to keep the groundstone stable during its utilization.

Experiment no.26—wild oat (*Avena sterilis*)

Surface morphometric analysis

At its natural state, the surface of experiment n. 26 is characterized by the presence of low and intermediate slopes (mean 12.9°) (Fig. 13a). A step, running across the center of the tool's surface, exhibits slopes ranging between 7.1° and 13.5°. The upper portion of the surface exhibits a gentle relief topography, in particular over its right-hand area, while, on the contrary, the lower portion of the surface is characterized by frequent low and intermediate slopes.

After being used, a decrease in the mean slope value was recorded, from 12.9° to 11.4°. Most of the low slopes which were visible on the surface before its use disappeared or were heavily leveled as in the case of the concentration of intermediate slopes present below the step. The latter were also modified by

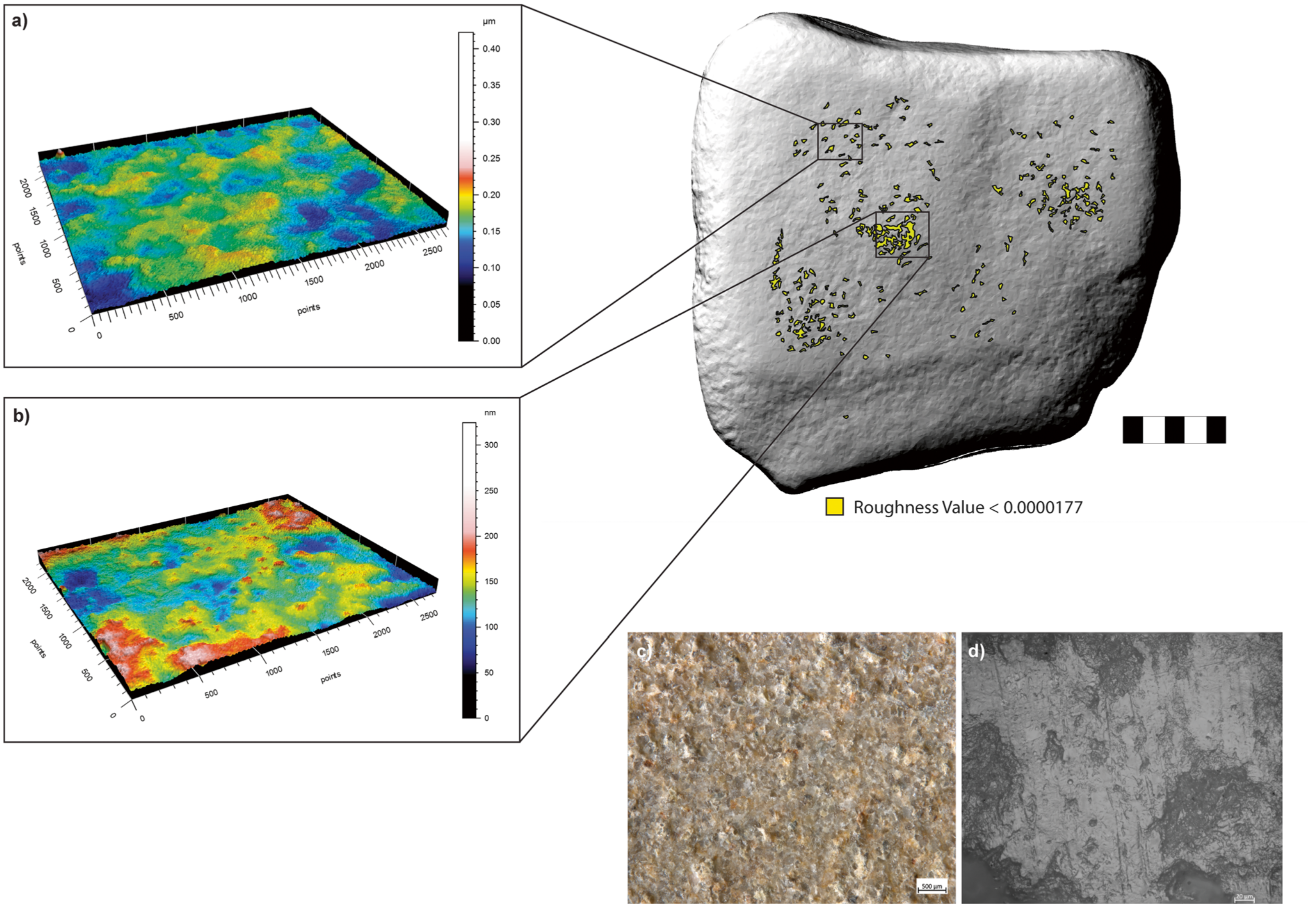

Fig. 11 Low roughness areas larger than 10 mm^2 developed over the groundstone surface after its use to process Foxtail millet grains (*Setaria italica*). **a**, **b** 3D rendering of the low roughness areas observed at 50x. **c**, **d** Surface leveling and polish observed at 80x and 200x magnifications

use, especially in its central portion which exhibits values ranging between 5.5° and 11.6° (Fig. 13b).

Before being used, the topography of the surface appeared heterogeneous (mean value 0.00019), with more homogeneous area localized over the top right portion of the groundstone. After its use, an increase in the overall topographic homogeneity of the surface was recorded as indicated by the mean roughness value 0.00012 (Fig. 13c). Low roughness areas (roughness value < 0.0000256) were well spread across the surface with the presence of medium sized (mean area 0.27 cm^2) homogeneous spots densely localized over the central portion of the groundstone (1.2 cm^2). At high magnifications, the low roughness areas appeared leveled with the presence of macro and micro cracks (Fig. 14c). Polishes exhibiting a rough to smooth texture and domed topography have been identified (Fig. 14d), along with deep chaotic striations characterized by a loose-separated distribution.

Residue spatial distribution

With the naked eye, macro residues are mostly packed over the central area of the surface. A total of 345 compounds have been identified over the surface of the groundstone. These are mostly localized (n. 195) over the lower left corner of the tool (square 4), which corresponds to the area less utilized during the grinding of *Avena sterilis*. On the contrary, very few compounds have been identified over the other portions of the surface (squares 2, 3, 5, and 6), which have been mostly utilized during the grinding activity (Fig. 15a–d). Here, a very large number of damaged starches was recorded (theoretical n. 5726), in particular in squares 5 (n. 3800) and 2 (theoretical n. 800).

Discussion

To date, the potential of 3D modeling and GIS software to analyze surface modification patterns on groundstones

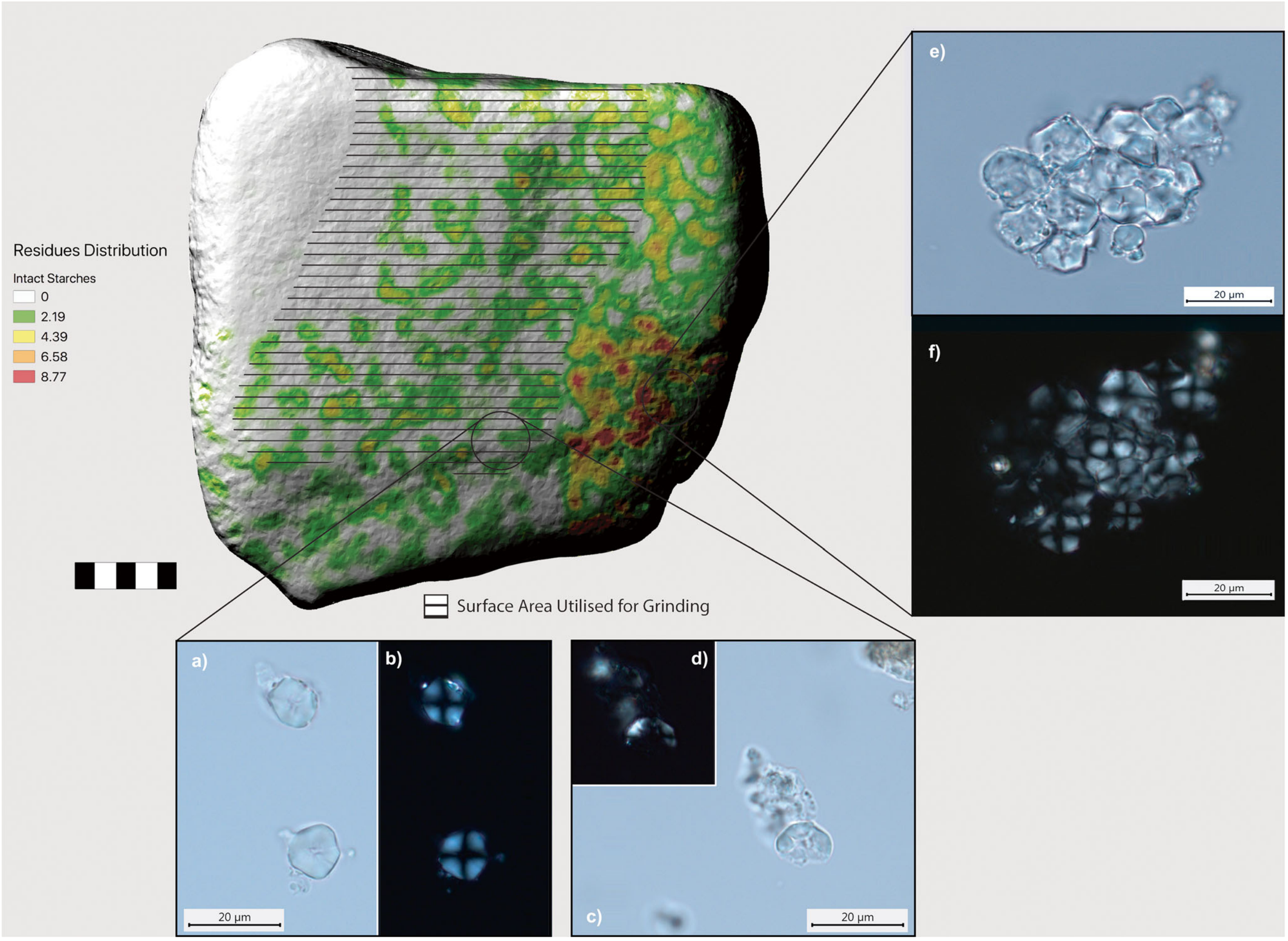

Fig. 12 Starch granule disposition over the surface of the groundstone utilized to grind Foxtail millet grains (*Setaria italica*). **a**, **b** Isolated starch grains with a polyhedral shape and centric hilum. **c**, d Single damaged starch granules. **e**, **f** Lump of polyhedral starch granules. Notice the strong birefringence of the granules in polarized light

utilized to work with wild plants has been underestimated. There are also only few applications of GIS to study the distribution of residues over the surface of macro lithic tools. Despite the limited number of experiments and the need for further trials in order to monitor variables which may affect surface modification and residues' disposition on groundstone surfaces, our combined approach allowed us to identify several variations in patterns of surface modification and in the distribution of residues caused by grinding/pounding activities (Table 6).

Overall, each of the macro lithic tools suffered a leveling of the surface, which happened at different degrees (Fig. 16d). The processing of *Rumex crispus* (curly dock) fruits led to a loss of 0.9° in the overall surface slope. This phenomenon is related to the development of the largest (mean area 0.5 cm^2) low roughness areas identified within the experimental sample. When observed at high magnifications, the latter ones correspond to portions of the surface where the grains amalgamate, and a smooth domed polish developed over their upper parts.

The groundstone utilized to process *Avena sterilis* (wild oat) grains exhibited the highest amount in slope decrease (1.5°), which corresponds to a very high degree of leveling of the topographic asperities present across the surface. Even though it features the higher degree of surface leveling, the visible low roughness areas are different if compared to the ones generated by the grinding of curly dock fruits. These are indeed smaller (mean area 0.3 cm^2) and well dispersed over the utilized area of the groundstone (density 0.7 cm^2). Also, when observed at high magnification, differences are visible in terms of use wear (Table 7). In particular, macro-fractures, which were not observed on the groundstone utilized to process curly dock fruits, characterize the utilized area of experiment 26. These are probably produced by the regular contact between the groundstone and the hammerstone during use, which