



HAL
open science

Sickle Gloss Texture Analysis Elucidates Long-Term Evolution of Plant Harvesting During the Transition to Agriculture

Juan José Ibañez, Patricia C. Anderson, Amaia Arranz-Otaeogui, Jesus Emilio Gonzalez Urquijo, Anne Jörgensen-Lindahl, Niccolo Mazzucco, Fiona Pichon, Tobias Richter

► **To cite this version:**

Juan José Ibañez, Patricia C. Anderson, Amaia Arranz-Otaeogui, Jesus Emilio Gonzalez Urquijo, Anne Jörgensen-Lindahl, et al.. Sickle Gloss Texture Analysis Elucidates Long-Term Evolution of Plant Harvesting During the Transition to Agriculture. *Journal of Archaeological Science*, 2021, 136, pp.105502. 10.1016/j.jas.2021.105502 . hal-03406802

HAL Id: hal-03406802

<https://hal.science/hal-03406802v1>

Submitted on 3 Jan 2025

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



Distributed under a Creative Commons Attribution - NonCommercial - NoDerivatives 4.0 International License



Sickle gloss texture analysis elucidates long-term change in plant harvesting during the transition to agriculture

Juan J. Ibáñez-Estévez^{a,*}, Patricia C. Anderson^b, Amaia Arranz-Otaegui^{c,e},
Jesús E. González-Urquijo^d, Anne Jörgensen-Lindhahl^e, Niccolò Mazzucco^{a,f}, Fiona Pichon^{a,g},
Tobias Richter^e

^a Consejo Superior de Investigaciones Científicas, Institución Milá y Fontanals de Investigación en Humanidades, 08001, Barcelona, Spain

^b Univ. Nice Sophia Antipolis, CNRS, CEPAM, UMR 7264, 06300, Nice, France

^c UMR 7209, Archéozoologie, Archéobotanique: Sociétés, Pratiques et Environnements Batiment 57, 55 rue Buffon, 75005, Paris, France

^d Universidad de Cantabria, IIPC (Universidad de Cantabria, Santander, Gobierno de Cantabria), 39005, Santander, Spain

^e Centre for the Study of Early Agricultural Societies, University of Copenhagen, 2300, Copenhagen, Denmark

^f University of Pisa, Department of Civilizations and Forms of Knowledge, Via dei Mille 19, 56126, Pisa, Italy

^g UMR5133-Archeorient, Environnements et Sociétés de l'Orient ancien, CNRS, 69365, Lyon, France

ARTICLE INFO

Keywords:

Harvesting
Neolithic
South West Asia
Usewear
Confocal microscopy

ABSTRACT

Archaeobotanical and genetic analysis of modern plant materials are drawing a complex scenario for the origins of cereal agriculture in the Levant. This paper presents an improved method for the study of early farming harvesting systems based on the texture analysis of gloss observed on sickle blades through confocal microscopy. Using this method, we identify different plant harvesting activities (unripe, semi-ripe and ripe cereal reaping and reed and other grass cutting) quantitatively and evaluate their change during the time when plant cultivation activities started and domesticated crops appeared in the Levant (12 800–7000 cal BC). The state of maturity of cereals when harvested shifted over time from unripe, to semi-ripe and finally to ripe. Most of these changes in harvesting techniques are explained by the modification of crops during the transition to agriculture. The shift in plant harvesting strategies was neither chronologically linear nor geographically homogeneous. Fully mature cereal harvesting becomes dominant around 8500 cal BC in the Southern Levant and one millennium later in the Middle Euphrates, which accords with the appearance of domestic varieties in the archaeobotanical record. The change in plant harvesting method fits better with the gradualist model of explanation of cereal agriculture than with the punctual one.

1. Introduction

Wheat and barley were first cultivated and domesticated in the Levant (Harlan, 1995; Zohary, D. & Hopf, 2000). However when and where wild cereal cultivation and the exploitation of domestic varieties took place, which are crucial questions for understanding why and how hunter-gatherers became farmers, are matters of vivid debate, in which an abrupt (core area) model is opposed to a progressive (protracted) one. The first model proposed that domestication occurred through conscious genetic selection of mutant individuals in a short period of time, circa 8500 cal BC, around the Karacadag area in South Turkey (Lev-Yadun et al., 2000; Abbo et al., 2010; Abbo and Gopher, 2020). However, during the last decade, new studies have pointed to a more complex,

multi-regional and protracted scenario for the origins of agriculture (Fuller et al., 2011; Fuller et al., 2012; Fuller et al., 2012; Jones et al., 2013; Pankin et al., 2018; Arranz-Otaegui et al., 2016). Archaeobotanical data suggest that cereal domestication was the result of a series of events occurring at different places over thousands of years, during which wild wheat persisted in cultivated fields, with the process occurring at varying rates in different areas of southwest Asia (Tanno and Willcox, 2006; Arranz-Otaegui et al., 2016). Genomic analysis is showing the enormous complexity of the evolutionary history of the cereal domestication process, indicating genetic ancestry from numerous geographic regions and diverse wild gene pools (Kilian et al., 2007; Civián et al., 2013; Poets et al., 2015; Pankin et al., 2017; Haas et al., 2019; Oliveira et al., 2020).

* Corresponding author. Juan J. Ibáñez-Estévez

E-mail addresses: ibanezjj@imf.csic.es (J.J. Ibáñez-Estévez), niccolo.mazzucco@unipi.it (N. Mazzucco), fiona.pichon@imf.csic.es (F. Pichon).

<https://doi.org/10.1016/j.jas.2021.105502>

Received 19 June 2021; Received in revised form 29 August 2021; Accepted 1 October 2021

Available online 26 October 2021

0305-4403/© 2021 The Authors.

Published by Elsevier Ltd.

This is an open access article under the CC BY-NC-ND license

(<http://creativecommons.org/licenses/by-nc-nd/4.0/>).

The analysis of sickle elements through use-wear analysis can offer a complementary source of information to archaeobotanical and genetic studies for disentangling this complex scenario (Anderson, 1992; Unger-Hamilton, 1992). Sickle blades were crucial in the process of cereal domestication, as reaping with lithic tools allowed the preferential selection of mutant seeds with a solid rachis that most probably led to domestication (Hillman and Davies, 1990). Sickle blades are present in Natufian sites and become progressively more common throughout the Pre-Pottery Neolithic period, thus from ca. 13 000–7000 cal BC, during the whole process of transition towards agriculture (Maeda et al., 2016). Silica-rich plants (and cereal) cutting generates polish on the tool edge that, after some hours of use, can be observed macroscopically as a sheen that is called sickle gloss. The standard method of use-wear analysis relies on the microscopic observation and the visual comparison and matching of use-wear on experimental and archaeological tools (Plisson, 1985; van Gijn, 1989). This method was used in the 1990s for the study of the origins of cereal agriculture, through the analysis of sickle gloss. A tendency to observe flatter and more abraded gloss in the later phases was attested (Anderson, 1992; Unger-Hamilton, 1992). This was related to the progressively riper harvesting and the more common low cutting of cereals (Anderson, 1992). However, the qualitative use-wear analysis is insufficient to clearly discriminate between tools used to cut different types of plants. During the last decade, a new quantitative method based on texture analysis of 3D use-wear polished surfaces, using confocal microscopy (Evans and Donahue, 2008; Ibáñez et al., 2019; Evans and Macdonald, 2011; Stemp and Chung, 2011; Stemp et al., 2015a, 2015b, 2018; Stevens et al., 2010; Ibáñez et al., 2019), is offering unprecedented precision and greater objectivity in the

identification of the plants that were cut with lithic tools (Ibáñez et al., 2014; Ibáñez et al., 2016; Pichon et al., 2021). In previous papers (Ibáñez et al., 2016; Pichon et al., 2021; Borrell et al., 2020), we used this methodology to study cereal harvesting in some Late Natufian and Early Neolithic sites. In this study, we have improved our methodology (see below) and included new sites from the Middle Euphrates (Jerr el Ahmar -PPNA- and Abu Hureyra -MPPNB-) and Southern Levant (Kharaysin -Middle PPNB, Early PPNB and Late PPNA-, Tell Qarassa North -Early PPNB-, Shubayqa 1 -Natufian- and Shubayqa 6 -Natufian and PPNA-). This has allowed us to compare changes in harvesting strategies which took place in the Northern and the Southern Levant.

Our methodology (see below) is based on the quantitative analysis of gloss texture on experimental tools used to cut five plant categories. These included three types of cereals: 1) morphologically domestic (*Triticum monococcum*, *T. aestivum*, *T. dicoccum* and *T. spelta*), 2) morphologically wild but cultivated (*T. boeoticum thaouard*) and 3) wild cereal species growing in natural stands (*T. boeoticum*, *T. dicoccoides* and *Hordeum spontaneum*), plus 4) reeds (*Phragmites communis*) and 5) another grass (*Ampelodesmos mauritanica*). The three categories of cereals were harvested at the point of maturity when it was possible to maximize the yield. This resulted in harvesting in an unripe state for spontaneously growing wild cereals, in a semi-ripe state for cultivated wild cereals and in a ripe state for domestic cereals. Gloss on experimental tools used in these five plant-cutting activities was scanned using confocal microscopy and 3D surfaces were obtained from these readings. These surfaces were measured using 25178 ISO parameters of texture analysis. Discriminant function analysis was used to obtain predictive algorithms (based on Bayes' theorem) for the classification of



Fig. 1. Map with the archaeological sites where the analyzed sickle blades were found.

archaeological tools in one of the five experimental categories. To test the discriminant capacity of the method, one half of the 3D surfaces were classified against the other half, obtaining a good rate of correct grouping. This method was used to analyze 215 sickle elements from nineteen archaeological sites/periods in Northern and Southern Levant dating from ca. 12 800–7000 cal BC (Natufian to Late PPNB periods) (Fig. 1). These sites and time span cover the period and regions where cereal cultivation and domestication took place during the transition from hunting-gathering to farming societies.

2. Methodology

2.1. Confocal microscopy and texture analysis

Use-wear analysis, a method pioneered by S. Semenov (1964), is based on the comparison between use-wear traces (microscarring, rounding, striations and use-polish) on experimental and archaeological tools in order to infer the function of the latter. This comparison is performed visually, using qualitative criteria. Among the different kinds of use-wear traces, use-polish is the most relevant one, as it allows the identification of the worked material. Plant (and cereal) cutting generates use-polish on the tool edge that -after some hours of use-can be observed macroscopically as a sheen that is called sickle gloss. Since the late 1980s, several studies have been carried out in order to obtain quantitative criteria for the characterization of use-polish (Beyries et al., 1988; Vila and Gallart, 1991; Anderson et al., 2006; González-Urquijo and Ibáñez, 2003). Nevertheless, it is through the development of confocal microscopy and texture analysis that these trials have definitively moved forward (Evans and Donahue, 2008; Stemp, 2014; Ibáñez et al., 2019; Watson et al., 2016; Calandra et al., 2019a; Macdonald et al., 2018, 2019; Martisius et al., 2018; Rosso et al., 2017; Pedergnana et al., 2020; Díaz-Bonilla et al., 2020; Álvarez-Fernández et al., 2020). We have contributed to this line of research by working on the discrimination of use-polish (gloss) caused by cutting different types of plants (Ibáñez et al., 2014, 2016).

A preliminary version of our methodological approach was previously described (Ibáñez et al., 2014, 2016). In the improved version presented in this paper we have included an experiment of cutting one type of grass ethnographically used for making handicrafts (baskets, mats, cords ...) and as fodder. Other methodological changes with respect to the previous versions are described below. The archaeological and experimental tools were cleaned with soapy water in an ultrasonic tank. The areas of gloss to be measured were chosen from among the zones where it is well developed. Between six and ten areas with harvesting gloss $650 \times 500 \mu\text{m}$ in size were scanned on the experimental and archaeological tools with the Sensofar Plu Neox confocal microscope, using a 20X (0.45 NA) objective, with a spatial sampling of 0.83 mm, an optical resolution of 0.31 mm, a vertical resolution of 20 nm and a z-step interval of 1 mm. A recent study suggests that the $500\times$ objective with higher numerical aperture could offer better discriminant results (Calanda et al., 2019b), which should be explored in future research. In our study, a 99,5% of the surface was scanned with the confocal microscope, while the rest of the area (0,05%) was not considered, in order to avoid measurement noise. The non-scanned points were later filled in before measuring the surface. The 3D surfaces were sampled, processed and later measured with the Mountain 7 software, from Digital Surf. Several samples of $200 \times 200 \mu\text{m}$ were taken from the $650 \times 500 \mu\text{m}$ areas. In many cases three samples of $200 \times 200 \mu\text{m}$ were taken from the $650 \times 500 \mu\text{m}$ areas, totaling around 20 samples per tool. The samples were chosen in the areas where microwear polish was homogenous and well developed and did not show irregularities caused by the natural surface of the flint. A leveling operator using the Least Squares (LS) Plane Method was employed to correct for the lack of horizontality of the 3D surface. To separate polish texture associated with the characteristics of the worked material from the irregularities of the flint surface, a spatial filtering was used, consisting of moving a small

filtering matrix (called a kernel matrix) over the surface. The arithmetic mean operator consists of averaging each point with its 13×13 neighboring points. The microtexture that is going to be measured is calculated by subtracting the filtered surface from the source surface.

Several areal surface parameters defined in ISO 25178 were selected on the basis of their discriminant capacity for the five experimental categories taken into account in this study:

- 1) Amplitude parameters, a class of surface finish parameter characterizing the distribution of heights (Sa, the mean height of the surface; Sq, the square root mean height; Sz, the distance between the highest peak and the deepest valley; Sp, the maximum peak height and Sv, maximum valley depth area).
- 2) Spatial parameters, which quantify the lateral information present on the X and Y-axes of the surface based upon spectral analysis (Sal, expressing the content in wavelength of the surface; Str, which measures whether the surface is isotropic).
- 3) Hybrid parameters considering both the amplitude and the spacing (Sdq, the root mean-square value of the surface slope; Sfd, indicating the complexity of the surface using the fractal dimension theory).
- 4) Parameters measuring the micro-valley network, obtained after the vectorization of the surface, searching for all the furrows in a surface and measuring their mean depth (MDF) and mean density (MDenF).

Quadratic discriminant function analysis was used to build a predictive model for group membership, which is composed of discriminant functions based on quadratic combinations of predictor variables when these variables show different variance-covariance matrices. The classification rule of the predictive analysis is based on the Bayes' theorem. This type of statistics is very sensitive to the presence of outliers, which can distort the final result of the classification. Because of this, for the experimental tools, the outliers for the eleven parameters used in the analyses were eliminated (amounting to 10% of the measured areas). For this, cases greater than three times the Interquartile Range were eliminated. These outliers are most probably caused by irregularities in the natural flint surface or are measurement noise generated by the confocal microscope.

2.2. The experimental program (Table 1)

The experiments based on harvesting wild cereals growing in natural stands were carried out in the Jebel el Arab, Southern Syria, in mid and late May 1995 and 1996 by P. Anderson. Stands of *Triticum boeoticum* were harvested at a phase when most of the stems were just yellowing and the first grains had detached from the seed head, but before complete maturity. Sickles with wooden and antler handles were used over 11–13 h, with fine-grained flint inserts (Fig. 2a and b). In the same region, in 2009 and 2010, stands of *Triticum dicoccoides* and *Hordeum spontaneum* were harvested by J.J. Ibáñez for over 4 h at the beginning of June, when the grain was already formed, but the plants were not completely ripe. We used a slightly curved sickle with a wooden handle, into which one obsidian and three fine-grained flint elements were inserted (Fig. 3a and b). *Hordeum spontaneum* (wild barley) was harvested using a bladed wooden sickle in 1993 in the Jordan Valley, Israel, for 2 h by Francois Valla for P. Anderson (Fig. 4a and b). In all these experiments, wild cereal stems were held in groups in the hand and were cut as close to the ground as possible, usually about 20 cm from it.

Cultivated wild cereals (*Triticum boeoticum thaouadar*) were experimentally sown and harvested in the grounds of the CNRS laboratory in the Institut de Préhistoire Orientale, Jalès, Ardèche, in a Mediterranean region of Southern France, between 1989 and 1994 (Anderson, 1992; Willcox, 1992). Two-grained wild einkorn gathered in Eastern Turkey was imported, cultivated and harvested in controlled conditions. Broadcast sowing was carried out near the time of natural grain dispersal, between late June and August. Cultivated wild cereals were reaped between early June and mid-July, when the grain was near

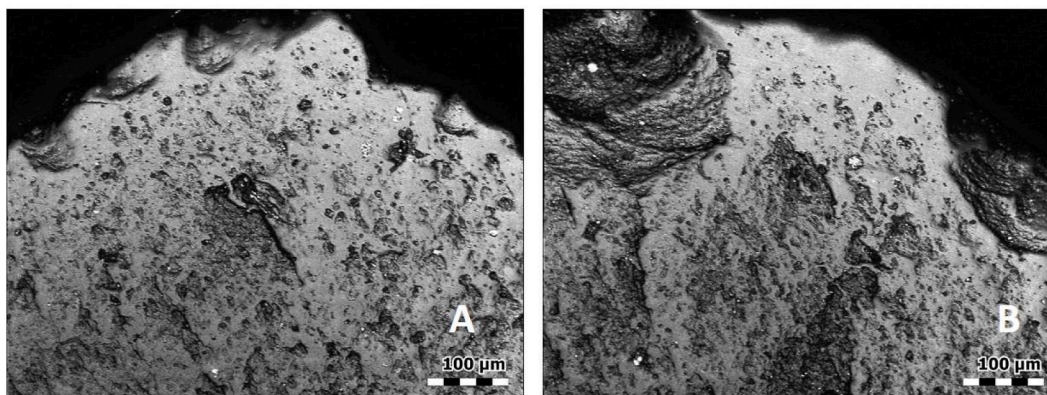


Fig. 2. a & b. Usewear polish from harvesting wild cereal in natural stands (*T. boeoticum*).

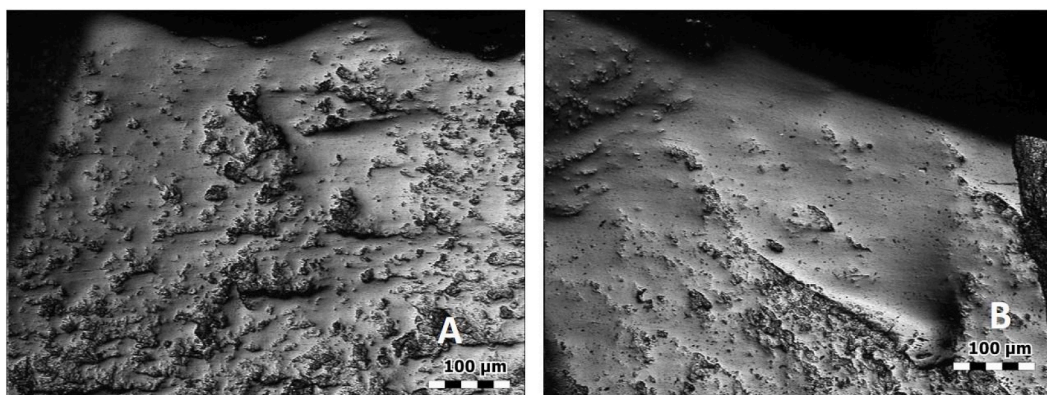


Fig. 3. a & b. Usewear polish from harvesting wild cereal in natural stands (*Hordeum spontaneum* and *T. diccoides*).

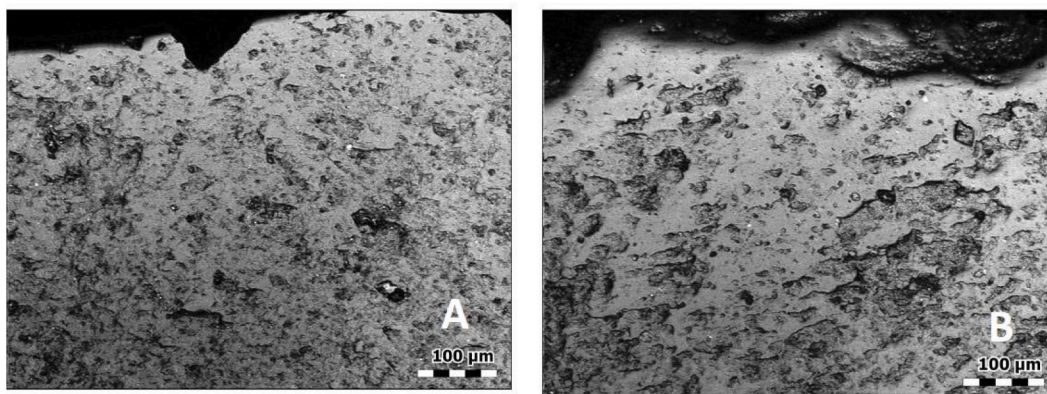


Fig. 4. a & b. Usewear polish from harvesting wild cereal in natural stands (*Hordeum spontaneum*).

maturity and most was still attached to the stem. At this semi-ripe stage, in which the stems at the height of the cut were a mixture of yellow and green, the plants could be harvested without a significant loss of the grain (Fig. 5a, b, c & d). Why can cultivated wild cereals be harvested in a riper state than wild cereals growing in natural stands? Synchronous planting and harvesting leads to more homogeneous ripening even after very few generations of cultivated cereals (Harlan, 1992), as happened in the experimental fields of Jalès, where wild cereals were sown very densely on rich soil, and the plots developed thick stands that matured uniformly (Willcox, 1992). The domestication syndrome involves several traits, one of them being the synchronous germination and maturing of the plants (Fuller 2007). This is not observed in wild cereal

stands, where plants mature at different times and rhythms, and they have to be collected green. We consider that if plants were systematically sown, they would eventually start germinating and maturing synchronously. This would allow cultivated wild cereals to be collected in a more advanced stage of maturity stage than wild, uncultivated/managed, cereal stands.

Experiments harvesting domestic cereals included cutting spelt (*Triticum spelta*) for 7 h and 4 1/2 h in Zureda (Asturias) in September 1994 by J.E. González-Urquijo y J.J. Ibáñez (Fig. 6a and b); einkorn (*Triticum monococcum*) in Seranon, Southeast France, for 4 1/2 h by P. Anderson (Fig. 7a and b); and another tool used for harvesting bread wheat (*Triticum aestivum*), emmer wheat (*Triticum dicoccum*) and

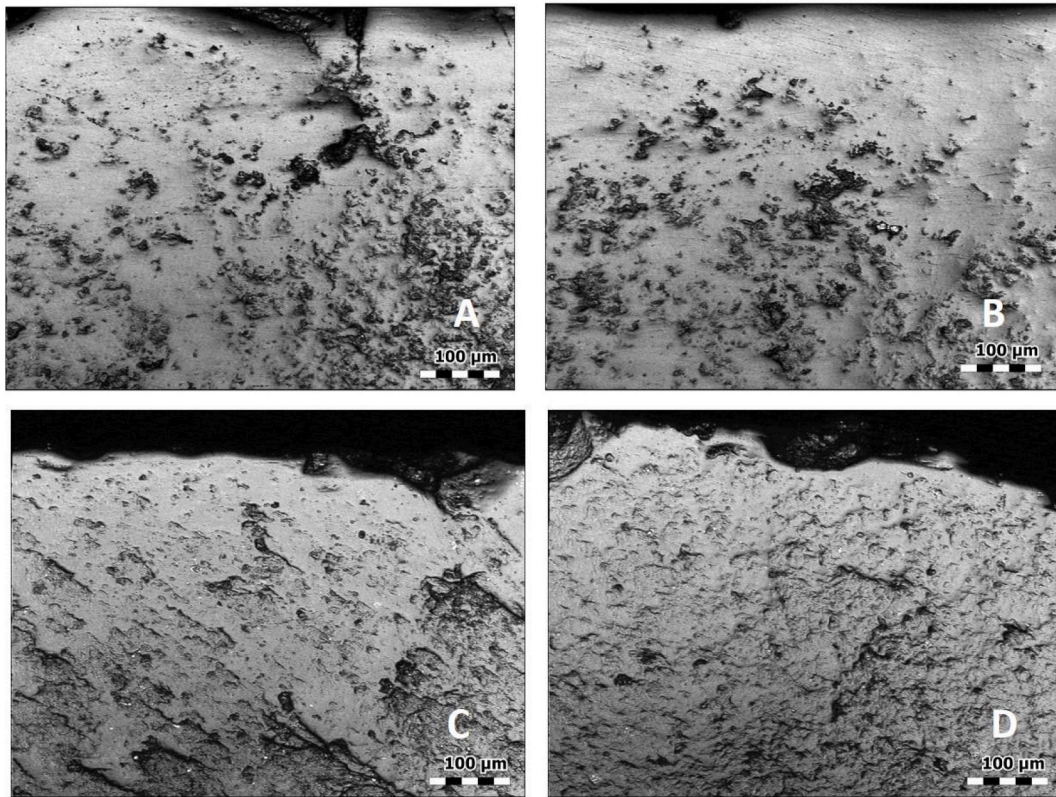


Fig. 5. a, b, c & d. Usewear polish from harvesting cultivated wild cereals (*Triticum boeoticum thaouidar*).

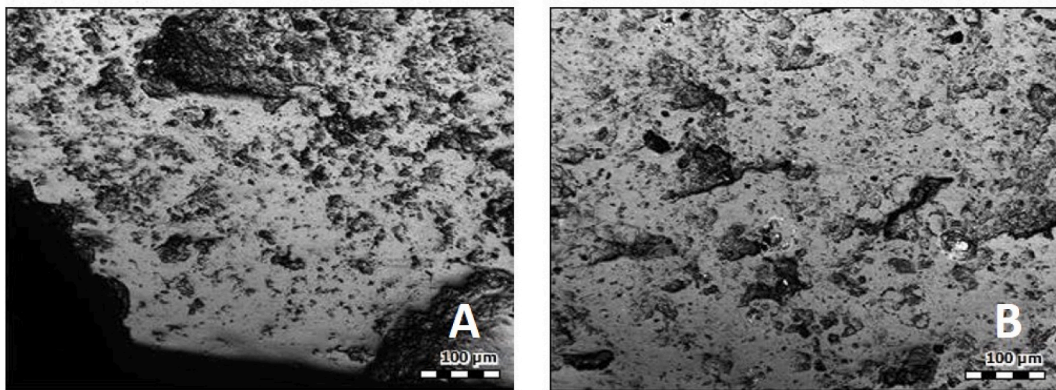


Fig. 6. a & b. Usewear polish from harvesting domestic cereals (*Triticum spelta*).

einkorn (*Triticum monococcum*) for 13 h in 1997 at Jalès by P. Anderson (Fig. 8a and b). In all these experiments the stems were cut when they were ripe at a height of approximately 20 cm from the ground.

Reed-cutting experiments (*Phragmites australis*) were carried out in Jalès (France) by P. Anderson, in shallow standing water, and when the stems were firm but not brittle (Fig. 9a and b). Grass-cutting experiments were carried out in Tunisia by P. Anderson (2014) (Fig. 10a and b). *Ampelodesmos mauritanica* is a fibrous grass related to the Stipeae tribe called dis or diss in Arabic. It is sickle-harvested and used as fodder, for making baskets, mats, ropes and whips, and for roofing huts (Novellino, 2006). Many plants other than cereals which were used by Neolithic groups (Sparta grass, *Stipa* or *Juncus*) are harvested by pulling them up, according to ethnographic observation (Rivera and Obón, 1991; Anderson & M'hamdi, 2014). In total, twenty experiments were carried out for this study (Table 1).

Usewear polish generated by working different materials can be

compared and the worked material identified after polish has developed sufficiently, surpassing the stabilization phase. In the experimental program, different times of use were carried out. In all cases, the use caused macroscopic gloss and the blind classification resulted in a good rate of correct grouping. The archaeological tools were sampled because of the presence of macroscopic gloss, observable to the naked eye. Therefore, both the experimental and the archaeological tools presented well developed polished that clearly surpassed the first steps of usewear polish development, in which the worked material cannot be confidently identified.

2.3. Classification of experimental tools

The discriminant function analysis consistently groups the surfaces of use-wear polish resulting from cutting the three cereal types (domestic, wild cultivated and wild in natural stands), reeds and grass.

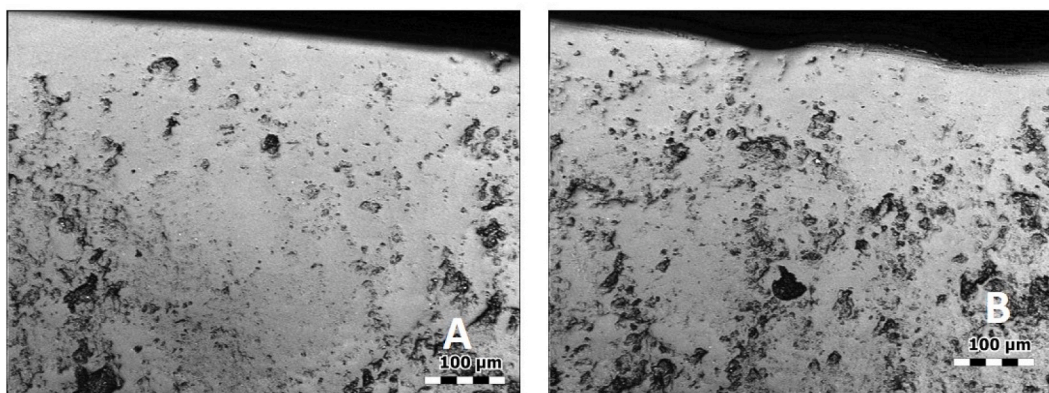


Fig. 7. a & b. Usewear polish from harvesting domestic cereals (einkorn, *Triticum monococcum*).

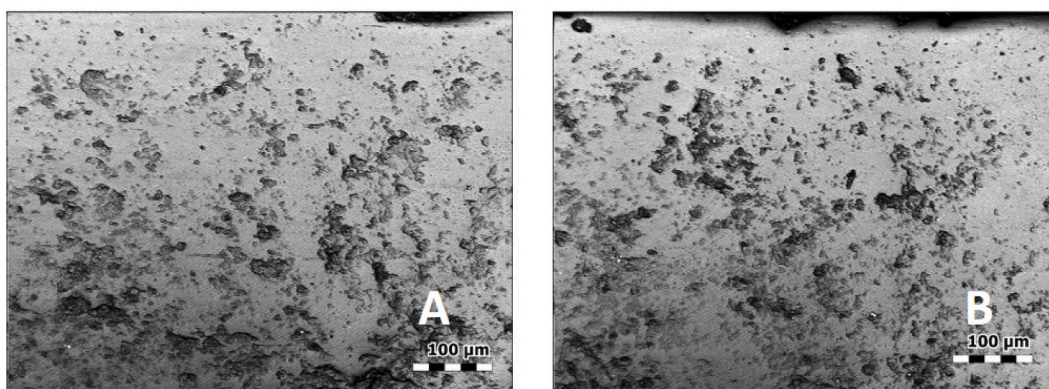


Fig. 8. a & b. Usewear polish from harvesting domestic cereals (bread wheat, *Triticum aestivum*; emmer wheat, *Triticum dicoccum* and einkorn, *Triticum monococcum*).

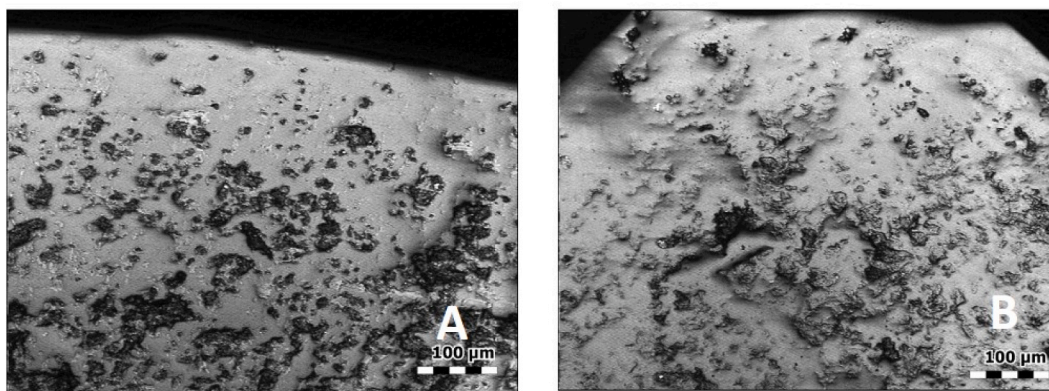


Fig. 9. a & b. Usewear polish from harvesting reeds (*Phragmites australis*).

Significant mean differences (Wilks' Lambda) were observed for all the predictors mentioned in the previous section and for discriminant functions. While the log determinants were quite similar, Box's M indicated that the assumption of equality of covariance matrices was violated, so a quadratic discriminant analysis was chosen. The Eigenvalue values show that Function 1 explains 47.7% of the variance, Function 2, 33.1%, Function 3, 13.2% and Function 4, 6%. The structure matrix showed main within-group correlation between variables Sa, Sq, MdF, Sdq, MDenF and Str with the first function, Sal and Sfd with the third and Sz, Sv and Sp with the fourth. The classification table shows 73% correct classification of the five groups of plant use-polish (Table 2).

The classification of the 3D surface of each experimental tool offers a

good image of the capacity of correct identification of the method (Table 3). Using the threshold of 45% correct classification of samples to consider each experimental tool as correctly classified (20% correct classification would correspond to the random grouping in five categories), all the experimental tools can be considered as correctly grouped.

However, to test more confidently the real predictive capacity of the method, we blindly classified half of the samples against the other half, so one half of the experimental samples were used to test the degree of correct classification of the other half. For this, no group was attributed to one half of the samples of each experimental tool and these blind samples were classified against the other half. Using this procedure and considering 45% correct classification of the samples from each tool as

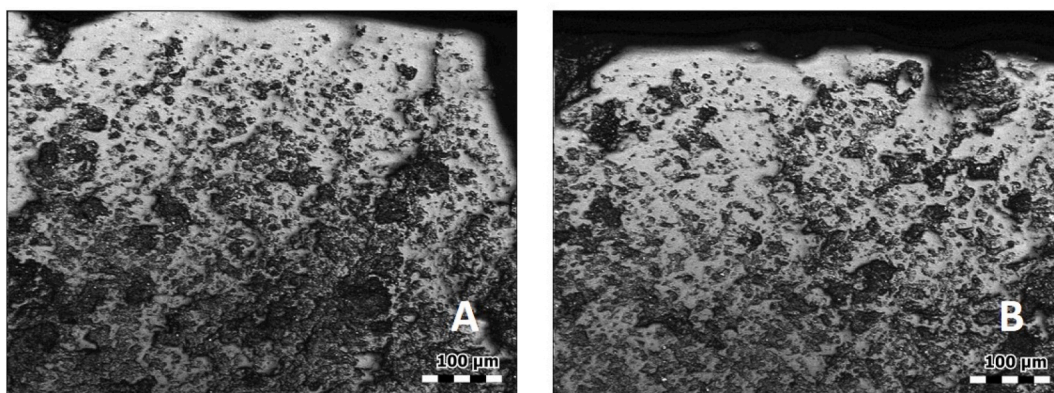


Fig. 10. a & b. Usewear polish from harvesting grass (*Ampelodesmos mauritanica*).

the threshold to categorize each experimental tool as correctly classified, we obtained good predictive results. Eighteen tools were correctly classified, while two can be considered as indeterminate, in which the threshold of 45% of the samples is not reached for any of the five categories (Table 4).

Our classificatory method allows a good rate of correct determination for the five categories of plant gloss texture, finding significant differences between the tools used for cutting the five plant categories in terms of roughness, isotropy, wavelength, complexity, depth and density of furrows and slope of surface points (Tables 5 and 6). The threshold of 45% of samples classified in one of the five groups permits a confident determination of the type of plant that was cut with the tool with a small risk of indetermination. For all the tools, the proportion of samples grouped in the five categories provides a good image of the relative importance of the plants that were reaped with them. The main risks of misclassification appear in samples corresponding to tools used to cut semi-ripe cereals, which may be classified as cutting ripe cereals (21% misclassification of 3D surfaces; Table 2) or tools used to cut reeds, which may be classified as cutting green cereals (15.9% misclassification of 3D surfaces; Table 2).

As a supplementary test to check the capacity of our method to correctly classify tools used for harvesting domestic cereals, which is a key element of our study, we blindly classified new samples by conducting three new experiments:

- 1 Harvesting einkorn (*Triticum monococcum*) in Seranon (France) for 10 h by F. Pichon,
- 2 Harvesting barley (*Hordeum vulgare*) in Burgos (Spain), for 8 h by J.J. Ibáñez.
- 3 Harvesting wheat (*Triticum aestivum*) in Tuscany (Italy), for 15 h by N. Mazzucco.

The classification of the three experiments was correct (as domestic cereal cutting) (Table 7).

2.4. The analysis of archaeological tools

The characteristics of the lithic raw materials in which the tools are made can affect use-wear polish quantification (Lerner et al., 2007). Our experimental programme was carried out using three different types of fine-grained flint, coming from Palmyra (Syria), Charente (France) and Treviño (Spain) (see Table 1). The classification of the experimental tools is good irrespectively of the type of flint in which the sickle element was made. This suggests that, as long as fine-grained flints are used, the origin of the raw material does not significantly affect the characteristics of harvesting gloss. All the archaeological tools analyzed in this study were made in fine grained flint. Post-depositional alterations can affect the identification of use-wear traces (Caux et al., 2018). Few studies

have tried to characterize post-depositional alterations quantitatively (Caux et al., 2018; Galland et al., 2019; Werner, 2018). J.J. Werner has demonstrated that medium and severe damage (shaking used tools during more than 60' in sediment) affects the identification of the materials that were worked with the tools. The only strategy available to deal with this issue is avoiding ensembles of tools with significant post-depositional alterations (Martisius et al., 2020). We have chosen archaeological tools with very low degree of alteration, which can be observed in the pictures of the gloss at 200x. Observed through the incident light microscope, the polished surfaces showed very slight or no alteration at all (see Figs. 14–40). As plant harvesting tends to create smooth surfaces, it is very easy to distinguish surfaces with low degree of alterations from surfaces with scratches, grooves, and other post-depositional abrasions. This strategy does not address the impact of potential alterations that cannot be perceived by human observation, which, in any case, would be very light. Another issue that can affect our capacity to identify the worked material is the length of use. Quantitative analysis of use-wear polish has shown that polish characteristics shift over time of use (Stemp and Stemp, 2003; Evans et al., 2014). However, the change fits a logarithmic function, so most texture modification takes place during the first phases of work (González-Urquijo and Ibáñez Estévez, 2003; Ibáñez and Mazzucco, 2021). This observation fits with Vaughan's model of polish development consisting of three successive phases: generic weak polish, smooth pitted polish, and well-developed polish. In this model, after the first phase of generic weak polish, each worked material develops specific use-wear polish characteristics (Vaughan, 1985). Thus, use-wear polish would reach a phase of stability in its development after a certain time of use what, joined to the fact that each type of use-wear polish evolves differently, explains our capacity to infer the worked material through the analysis of use-wear polish. The archaeological tools were sampled among those showing macroscopic gloss on the edges, and therefore well-developed usewear polish, avoiding tools in which a poor development of polish could jeopardize their correct identification. Moreover, even if our experimental tools were used during different periods, the blind classification resulted in a good rate of correct grouping. This suggests that, when the use-wear polish is well developed, the time of use does not affect decisively our capacity to identify the type of plant worked with the tool.

The archaeological tools were classified in one of the five categories of plant cutting-tools when more than 50% of the 3D surfaces were classified in one of the groups, otherwise, they were classified as indeterminate (Tables 8 and 9). The classificatory threshold was raised for archaeological tools (50%) compared with the experimental ones (45%) in order to reduce the rate of potential errors. In Table 8 we show the results of the classification of each archaeological tool and in Table 9 the quantity of tools classified in the six groups (five plant working groups plus indeterminate) per site/level. While in Table 9 we show the

Table 1

The experimental program. All the experiments except one of grass cutting were published in Ibáñez et al. (2014) and 2016.

Tool	Type of plant	Plant species	Year	Place	Time of use	Sickles
1	Domestic cereal	<i>T. spelta</i>	1994	Zureda, Asturias (Spain)	420'	One sickle
2	Domestic cereal	<i>T. spelta</i>	1994	Zureda, Asturias (Spain)	420'	
3	Domestic cereal	<i>T. spelta</i>	1994	Zureda, Asturias (Spain)	420'	
4	Domestic cereal	<i>T. spelta</i>	1994	Zureda, Asturias (Spain)	270'	One sickle
5	Domestic cereal	<i>T. monococcum</i>	2008	Seranon, Alpes-Maritimes (France)	270'	One sickle
6	Domestic cereal	<i>T. aestivum</i> <i>T. monococcum</i> , <i>T. dicoccum</i>	1997	Jalès, Ardèche (France)	900'	One sickle
7	Wild cereal in natural stands	<i>Hordeum spontaneum</i> and <i>T. diccoides</i>	2009	Jebel el Arab (Syria)	240'	One sickle
8	Wild cereal in natural stands	<i>Hordeum spontaneum</i> and <i>T. diccoides</i>	2009	Jebel el Arab (Syria)	240'	
9	Wild cereal in natural stands	<i>Hordeum spontaneum</i> and <i>T. diccoides</i>	2009	Jebel el Arab (Syria)	240'	
10	Wild cereal in natural stands	<i>Hordeum spontaneum</i>	1993	Jordan Valley (Israel)	120'	One sickle
11	Wild cereal in natural stands	<i>Hordeum spontaneum</i>	1993	Jordan Valley (Israel)	120'	
12	Wild cereal in natural stands	<i>T. boeoticum</i>	1995	Jebel el Arab (Syria)	720'	One sickle
13	Wild cultivated	<i>T. boeoticum</i>	1992	Jalès (France)	480'	One sickle
14	Wild cultivated	<i>T. boeoticum</i>	1992	Jalès (France)	600'	One sickle
15	Wild cultivated	<i>T. boeoticum</i>	1989	Jalès (France)	480'	One sickle
16	Wild cultivated	<i>T. boeoticum</i>	1989	Jalès (France)	760'	One sickle
17	Wild cultivated	<i>T. boeoticum</i>	1989	Jalès (France)	480'	One sickle
18	Reeds	<i>Phragmites communis</i>	1993	Jalès (France)	100'	One sickle
19	Reeds	<i>Phragmites communis</i>	1993	Jalès (France)	120'	One sickle
20	Grass	<i>Ampelodesmos mauritanica</i>	2012	Ain Salem (Tunisia)	80'	One sickle

classification of tools per site/level, we also considered the proportion of 3D surfaces classified in each of the five plant cutting groups per site/level (Tables 10 and 11; Figs. 11 and 12). Finally, the index of the degree of maturity of harvested cereals per level/site (Tables 12 and 13; Fig. 13) was calculated considering exclusively the results attributed to cereal harvesting in the three stages of maturity. The proportion of unripe harvesting was multiplied by three, semi-ripe harvesting by two and ripe harvesting by one and the addition was calculated. Thus, 300 would be the index of a site with exclusively unripe cutting and 100 for one with only ripe cutting.

In a previous version of our methodology (Ibáñez et al., 2016; Pichon et al., 2021), we only considered four categories of experimental plant-cutting tools: domestic cereals, wild cereals in natural stands, wild cultivated cereals and reeds. In this study we included grass cutting experiments (others than cereals and reeds) as, this activity could correspond to using grass in technological activities or as fodder. In the previous studies, the threshold of classification of archaeological tools in one of the groups was 60% of samples of 3D surfaces, while in this analysis (with one group of classification more) the threshold is 50%. In our previous approach, in a first step, we classified the tools in either cereal cutting or reed cutting groups and, in a second step, we classified those tools previously identified as used for cereal cutting in the three categories of cereal cutting tools (green, semi-ripe and ripe). Putting aside the indeterminate tools, we plotted the proportion of samples in the three categories by site/level in order to show the change of the degree of maturity of crops in the Middle Euphrates. However, in later research (Ibáñez et al., 2019) we found that the classification of tools using texture analysis is more precise when predicted membership is calculated for all the groups (ripe cereal, semi-ripe cereal, unripe cereal, reeds and other grass) in one step rather than in successive ones (i.e. discriminating first cereals from other grasses and, in a second step, identifying the state of maturity –ripe, semi-ripe and unripe–among those tools previously identified as used for cereal cutting). Thus, in our current approach we classify all the archaeological tools in the five experimental categories in a single step. Moreover, to plot the results by site/level we consider all the tools, without putting aside those classified as indeterminate, as we think that this procedure better shows the variability of gloss texture in archaeological sites/levels. Because of these changes, the results in the classification of the same tool and site/level can vary slightly in this study from the previous one, though the results in our previous paper and in this one are similar.

Gloss texture analysis finds significant differences between the tools used for cutting the five plant categories in terms of roughness, isotropy, wavelength, complexity, depth and density of furrows and slope of surface points (Table 6). The capacity of gloss texture analysis to separate the five plant-cutting activities is explained by the different mechanical characteristics of cereals, reeds and grass. Phragmites stems are 5–15 mm wide and rigid, cereal stems are 1.5–2.5 mm wide and more flexible, while *Ampelodesmos* leaves are 3–9 mm wide, very supple but tenacious. The degree of humidity in the stems/leaves is higher in reeds as they grow in swampy areas, medium for the *Ampelodesmos* grass while it is green and lower for cereals when they are cut in the late spring or summer. The capability to discriminate the three types of cereal-cutting gloss is probably due to different degrees of humidity present in the stems when reaped. When the aim of cereal cultivation is maximizing the yield, cereals are harvested in a state of maturity that is as advanced as possible. Morphologically domesticated cereals are usually reaped when they are ripe and the grains are fully mature. In contrast, wild cereal stands are commonly harvested before the plants reach maturation, that is when they are green or semi-green, because once fully mature, the spikelets start to disarticulate, leading to grain-loss (Anderson, 1992; Willcox, 1992). Interestingly, our method shows clear differences between the experimental tools used to harvest wild cereals from natural stands in Syria and Israel and those used to cut wild cereals cultivated in Jalès (France). Texture analysis places the use-wear created when harvesting cultivated wild cereals in an intermediate position, between wild spontaneous and domestic cereal cutting tools. To explain this discrimination, we suggest several possible explanations. 1) Synchronous planting and harvesting may lead to more homogeneous ripening even after very few generations of cultivated cereals (Harlan, 1992). 2) The wild cereal cultivation experiments carried out in Jalès demonstrated that the most productive yield is obtained when crops are in a semi-ripe stage, which lasts only for a few days. During this short period the seeds are more developed than in an unripe or green stage. Harvesting is thus more productive, yet at the same time, grain-loss is avoided, as the plants are not mature enough for the ear to disarticulate

Table 2

Predicted group membership through quadratic discriminant classification of the experimental samples; 73% of original grouped cases correctly classified. N represents the number of samples.

Experiment	Predicted group membership										
	Domestic		Wild stands		Wild cultivated		Reeds		Grass		Total
	N	%	N	%	N	%	N	%	N	%	N
Domestic	116	76.8	14	9.3	19	12.6	2	1.3	0	0	151
Wild stands	10	8.9	82	73.2	12	10.7	8	7.1	0	0	105
Wild cultivated	22	21.0	8	7.6	69	65.7	5	4.8	1	1.0	112
Reeds	3	6.8	7	15.9	3	6.8	31	70.5	0	0	44
Grass	0	0	0	0	0	0	0	0	15	100	15

Table 3

Predicted group membership through quadratic discriminant classification of the samples of each experimental tool. Correct classification in green.

Experiment	Predicted membership											
	Domestic		Wild stands		Wild cultivated		Reeds		Grass		Total	
	N	%	N	%	N	%	N	%	N	%		
1	Domestic	17	85.0	0	0	3	15.0	0	0	0	0	20
2	Domestic	31	72.1	6	14.0	6	14.0	0	0	0	0	43
3	Domestic	17	70.8	5	20.8	2	8.3	0	0	0	0	24
4	Domestic	18	81.8	1	4.5	3	13.6	0	0	0	0	22
5	Domestic	10	55.6	1	5.6	5	27.8	2	11.1	0	0	18
6	Domestic	23	95.8	1	4.2	0	0	0	0.0	0	0	24
7	Wild stands	5	25.0	9	45.0	3	15.0	3	15.0	0	0	20
8	Wild stands	2	13.3	9	60.0	2	13.3	2	13.3	0	0	15
9	Wild stands	2	9.1	16	72.7	3	13.6	1	4.5	0	0	22
10	Wild stands	1	4.5	18	81.8	1	4.5	2	9.1	0	0	22
11	Wild stands	0	0.0	19	90.5	2	9.5	0	0	0	0	21
12	Wild stands	0	0.0	11	91.7	1	8.3	0	0	0	0	12
13	Wild cultivated	5	26.3	3	15.8	11	57.9	0	0	0	0	19
14	Wild cultivated	5	25.0	1	5.0	14	70.0	0	0	0	0	20
15	Wild cultivated	5	23.8	1	4.8	14	66.7	1	4.8	0	0	21
16	Wild cultivated	6	25.0	3	12.5	11	45.8	4	16.7	0	0	24
17	Wild cultivated	1	4.8	0	0	19	90.5	0	0.0	0	0	21
18	Reeds	3	14.3	5	23.8	1	4.8	12	57.1	0	0	21
19	Reeds	0	0	2	8.7	2	8.7	19	82.6	0	0	23
20	Grass	0	0	0	0	0	0	0	0	15	100	15

Table 4

Predicted group membership through quadratic discriminant classification of the samples of each experimental tool after blindly classifying one half of the samples against the other half. Correct classification in green; indeterminate classification in yellow. N represents the number of samples. Notice that the number of samples from each experimental tool is approximately the half of the original samples observed in Table 3.

Experiment	Predicted membership											Total
	Domestic		Wild stands		Wild cultivated		Reeds		Grass			
	N	%	N	%	N	%	N	%	N	%	N	
1	Domestic	7	70	1	10	2	20	0	0	0	0	10
2	Domestic	13	61.9	3	14.3	5	23.8	0	0	0	0	21
3	Domestic	9	75	2	16.6	0	0	0	0	1	0	12
4	Domestic	10	81.8	1	4.5	0	13.6	0	0	0	0	11
5	Domestic	5	55.5	0	5.6	3	33.3	1	11.1	0	0	9
6	Domestic	11	91.6	1	8.3	0	0.0	0	0	0	0	12
7	Wild stands	3	30	4	40	1	10	2	20	0	0	10
8	Wild stands	0	0	6	75	0	0	2	25	0	0	8
9	Wild stands	0	0	9	81.8	2	8.2	0	0	0	0	11
10	Wild stands	0	0	10	90.9	0	0	1	9.1	0	0	11
11	Wild stands	0	0	9	90	1	10	0	0	0	0	10
12	Wild stands	0	0	5	83.3	1	16.7	0	0	0	0	6
13	Wild cultivated	3	30	2	20	5	50	0	0	0	0	10
14	Wild cultivated	2	20	20	5.0	6	60	0	0	0	0	10
15	Wild cultivated	2	20	1	10	7	70	0	0	0	0	10
16	Wild cultivated	4	33.3	1	8.3	5	41.6	2	16.6	0	0	12
17	Wild cultivated	1	10	0	0.0	9	90	0	0	0	0	10
18	Reeds	2	18.2	1	9.1	1	9.1	7	63.6	0	0	11
19	Reeds	0	0	1	9.1	1	9.1	9	81.8	0	0	11
20	Grass	0	0	1	12.5	0	0.0	2	25	5	62.5	8

Table 5
Mean of the parameters of texture of the five experimental groups.

Parameter	Meaning	Domestic	Wild cultivated	Wild in natural stands	Reeds	Grass
MDepthFur	Depth of furrows	0,291	0299	0,434	0605	0,497
MDenFur	Density of furrows	1196	1187	1179	1149	1197
Sa	Roughness	0,108	0115	0,170	0225	0,197
Sq		0,165	0174	0,249	0347	0,285
Sz		2277	2617	3060	5005	4957
Sp		1686	1930	2098	3727	2565
Sv		1454	1745	1881	2950	2392
Str	Isotropy	0,613	0638	0,588	0495	0,499
Sal	Wavelength	2654	2776	2635	2552	2321
Sdq	Slope of surface points	0,122	0130	0,185	0282	0,216
Sfd	Complexity	2507	2526	2555	2484	2557

Table 6
Comparative texture characteristics of gloss on experimental tools used for cutting the five categories of plants.

	High	Medium	Low
Roughness	Reeds, grass	Wild spontaneous	Wild cultivated, domestic, Reeds, grass
Isotropy	Domestic, wild cultivated	Wild spontaneous	Reeds, grass
Wavelength	Wild cultivated	Domestic, wild spontaneous	Reeds, grass
Complexity	Wild spontaneous, grass	Domestic, wild cultivated	Reeds
Depth of furrows	Reeds	Grass, wild cultivated	Domestic, wild cultivated
Density of furrows	Domestic, grass	wild cultivated, wild spontaneous	Reeds
Slope of surface points	Reeds	Wild spontaneous, grass	Domestic, wild cultivated

during harvesting (Willcox, 1992; Unger Hamilton, 1992). Besides, cultivated fields of wild cereals can be more thoroughly surveyed than natural stands, because they are located near villages, and thus they can be more easily harvested in a more advanced moment of maturity. 3) In natural stands, cereals flourished together with a mix of other plants that compete with them (Weide et al., 2021), including perennial grasses, while in cultivated fields the dominance of cereals is expected (because of clearance of the field or weeding). Thus, when harvesting spontaneously growing wild cereal stands, the diversity of plants harvested is greater than in cultivated fields, and includes green perennial grasses, which could affect gloss texture, increase roughness, complexity, density of furrows and slope of surface points, while decreasing isotropy and wavelength (see Table 6).

In our experimental model, we have distinguished five types of plant cutting activities, including harvesting green (wild in natural fields), semi-ripe (wild cultivated) and ripe (domestic) cereals. However, reality was surely more complex. Sickles could have been used for reaping different types of plants or cereals in different states of maturity. In fact, during the process of domestication of cereals, fields with different proportions of semi-solid or solid rachises most probably existed. This admixture of activities has not been experimented by us yet. In any case, the texture of gloss will be the average result of the characteristics of the reaped plants. Our assumptive expectation for the characteristics of

gloss in case of cutting different types of plants is: 1) The identification of the tool in one of the five plant working groups when most of the work was carried out in only one type of activity (i.e. ripe cereal harvesting); 2) The classification of the tool as “indeterminate” (less than 50% of the surface samples classified in any of the five plant working groups) when the tool was used for cutting different types of plants in a more balanced way. This classification as indeterminate is observed in a significant proportion of archaeological tools. Interestingly, this happens in higher proportion in the older periods, suggesting that sickles tended to be used more specifically (to cut just one type of plant or cereals in only one state of maturity) through time.

Our method enables a high confidence in the classification of cereal harvesting tools in three states of maturity: unripe, the state in which wild cereals in natural stands were harvested; semi-ripe, the condition in which experimental wild cultivated cereals were cut at Jalès; and ripe, the state in which domestic cereals were reaped. However, for archaeological tools, it is not possible to automatically equate the degree of humidity of cereal when harvested with a specific step in the process towards agriculture (i.e. unripe cutting = harvesting wild cereals in natural stands). Ripe stems of wild cereals could be harvested for feeding the livestock or for technical activities such as basketry or for roofing houses. Similarly, domestic cereals can be cut in a semi-ripe state, as, for example, for making *freekeh*, a kind of roasted snack where the taste of the unripe grain is sought. Environmental humidity/dryness can influence the degree of moisture of cereals when harvested. Another issue is the possibility that one sickle could have been used for cutting different types of plants. In this case, texture analyses would probably result in an indeterminate classification of the tool or in the classification of the tool in the group of dominant use. These factors have to be considered when interpreting the archaeological data. However, when information on gloss texture analysis is considered in conjunction with the archaeobotanical information, it is possible to evaluate how plant harvesting systems changed with the development of plant cultivation and domestication. In this work, we interpret the evidence by assuming that people in the past were trying to achieve the highest yield, which was most probably the goal during the origins of agriculture as this is a prerequisite for explaining the process of genetic selection leading to domestication. The change towards riper cereal harvesting from 12 800–7000 cal BC in both Northern and Southern Levant strongly suggests that these changes in harvesting strategies were related to crop management shifts that took place during the transition to agriculture.

Table 7
Blind classification of three experiments of harvesting domestic cereals. All three are well classified. N represents the number of samples.

Experiment	Predicted group membership									
	Domestic		Wild stands		Wild cultivated		Reeds		Grass	
	N	%	N	%	N	%	N	%	N	%
<i>Hordeum vulgare</i>	20	80	0	0	0	0	1	4	4	16
<i>Triticum monococcum</i>	23	76,7	0	0	0	0	5	16,7	2	6,7
<i>Triticum aestivum</i>	19	76,0	0	0	2	8,0	4	16,0	0	0

Table 8
Classification of archaeological tools. N represents the number of samples.

Period	Site	Tool	N						%				
			Ripe	Semi-Ripe	Unripe	Reeds	Grass	Total	Ripe	Semi-Ripe	Unripe	Reeds	Grass
LPPNB	Tell Halula	HL 2C 166	4	6	3	3	0	16	25,0	37,5	18,8	18,8	0,0
LPPNB	Tell Halula	HL 2C 223	2	11	5	2	0	20	10,0	55,0	25,0	10,0	0,0
LPPNB	Tell Halula	HL 2C 289	12	3	1	1	0	17	70,6	17,6	5,9	5,9	0,0
LPPNB	Tell Halula	HL 2C 291	13	2	0	0	0	15	86,7	13,3	0,0	0,0	0,0
LPPNB	Tell Halula	HL 2C 328	13	4	0	1	0	18	72,2	22,2	0,0	5,6	0,0
LPPNB	Tell Halula	HL 2C 1	12	5	1	0	0	18	66,7	27,8	5,6	0,0	0,0
LPPNB	Tell Halula	HL 2D 12	6	15	0	0	0	21	28,6	71,4	0,0	0,0	0,0
LPPNB	Tell Halula	HL 2D 2	9	11	0	1	0	21	42,9	52,4	0,0	4,8	0,0
LPPNB	Tell Halula	HL 2D 4	14	7	0	0	0	21	66,7	33,3	0,0	0,0	0,0
LPPNB	Tell Halula	HL 2D 44	4	17	0	0	0	21	19,0	81,0	0,0	0,0	0,0
								Mean	48,8	41,2	5,5	4,5	0,0
MPPNB	Tell Halula	HL 4C	7	5	2	1	0	15	46,7	33,3	13,3	6,7	0,0
MPPNB	Tell Halula	HL 4D A7	5	3	3	4	1	16	31,3	18,8	18,8	25,0	6,3
MPPNB	Tell Halula	HL 4D E68	3	8	7	0	0	18	16,7	44,4	38,9	0,0	0,0
MPPNB	Tell Halula	HL 4D element 1	13	2	2	1	0	18	72,2	11,1	11,1	5,6	0,0
MPPNB	Tell Halula	HL 4D element 2	12	0	3	0	0	15	80,0	0,0	20,0	0,0	0,0
MPPNB	Tell Halula	HL 4D element 3	10	6	2	0	0	18	55,6	33,3	11,1	0,0	0,0
MPPNB	Tell Halula	HL 4D 103	17	11	0	0	0	28	60,7	39,3	0,0	0,0	0,0
MPPNB	Tell Halula	HL 4D 131	9	11	0	8	0	28	32,1	39,3	0,0	28,6	0,0
MPPNB	Tell Halula	HL 4D 98	12	9	0	0	0	21	57,1	42,9	0,0	0,0	0,0
								Mean	50,3	29,2	12,6	7,3	0,7
EPPNB	Mureybet	Mb 72 500	10	8	2	0	0	20	50,0	40,0	10,0	0,0	0,0
EPPNB	Mureybet	Mb 74 1461	2	11	5	0	0	18	11,1	61,1	27,8	0,0	0,0
EPPNB	Mureybet	Mb 74 1614	12	6	0	0	0	18	66,7	33,3	0,0	0,0	0,0
EPPNB	Mureybet	Mb 74 1728	17	1	0	0	0	18	94,4	5,6	0,0	0,0	0,0
EPPNB	Mureybet	Mb 74 1779	1	4	9	1	2	17	5,9	23,5	52,9	5,9	11,8
EPPNB	Mureybet	Mb 74 1837	0	3	7	3	3	16	0,0	18,8	43,8	18,8	18,8
EPPNB	Mureybet	Mb 74 1857	13	6	1	0	0	20	65,0	30,0	5,0	0,0	0,0
EPPNB	Mureybet	MB IVA 1679	10	9	0	2	0	21	47,6	42,9	0,0	9,5	0,0
EPPNB	Mureybet	MB IVA 1976	1	20	0	0	0	21	4,8	95,2	0,0	0,0	0,0
EPPNB	Mureybet	MB IVA 2779	5	16	0	0	0	21	23,8	76,2	0,0	0,0	0,0
								Mean	36,9	42,7	13,9	3,4	3,1
PPNA	Mureybet	Mb 74 1236	11	6	1	0	0	18	61,1	33,3	5,6	0,0	0,0
PPNA	Mureybet	Mb 74 1384	1	1	15	1	0	18	5,6	5,6	83,3	5,6	0,0
PPNA	Mureybet	Mb 74 2132	5	5	5	0	0	15	33,3	33,3	33,3	0,0	0,0
PPNA	Mureybet	Mb IIIA 2135	0	0	0	18	0	18	0,0	0,0	0,0	100,0	0,0
PPNA	Mureybet	Mb 74 2287	0	3	11	3	0	17	0,0	17,6	64,7	17,6	0,0
PPNA	Mureybet	Mb 74 2976	3	13	0	0	1	17	17,6	76,5	0,0	0,0	5,9
PPNA	Mureybet	Mb 73 1031	3	3	1	3	1	11	27,3	27,3	9,1	27,3	9,1
PPNA	Mureybet	Mb 73 1034	10	8	0	0	0	18	55,6	44,4	0,0	0,0	0,0
PPNA	Mureybet	Mb 73 779	6	9	3	0	0	18	33,3	50,0	16,7	0,0	0,0
PPNA	Mureybet	Mb 74 303	7	0	10	1	0	18	38,9	0,0	55,6	5,6	0,0
PPNA	Mureybet	Mb 74 5509	9	9	0	0	0	18	50,0	50,0	0,0	0,0	0,0
PPNA	Mureybet	Mb IIIA 313	2	18	0	1	0	21	9,5	85,7	0,0	4,8	0,0
PPNA	Mureybet	Mb IIIA 9135	11	10	0	0	0	21	52,4	47,6	0,0	0,0	0,0
								Mean	29,6	36,3	20,6	12,4	1,2
Natufian	Mureybet	Mb Q33 B4	0	12	0	0	0	12	0,0	100,0	0,0	0,0	0,0
Natufian	Mureybet	Mb 71 Q33 B4 3888	0	5	9	3	1	18	0,0	27,8	50,0	16,7	5,6
Epi-Natufian	Mureybet	Mb 73 6430	2	15	2	0	0	19	10,5	78,9	10,5	0,0	0,0
Natufian	Abu Hureyra	PA 21	5	24	0	0	0	29	17,2	82,8	0,0	0,0	0,0
Natufian	Abu Hureyra	PA 22	10	7	4	0	0	21	47,6	33,3	19,0	0,0	0,0
Natufian	Abu Hureyra	AH 73 E271 F449	0	4	9	6	2	21	0,0	19,0	42,9	28,6	9,5
Natufian	Abu Hureyra	PA Abu Hureyra	3	3	6	5	1	18	16,7	16,7	33,3	27,8	5,6
								Mean	13,1	51,2	22,2	10,4	3,0
MPPNB	Abu Hureyra	AH72 23 F47 1	17	4	0	0	0	21	81,0	19,0	0,0	0,0	0,0
MPPNB	Abu Hureyra	AH72D 32 F71	0	21	0	0	0	21	0,0	100,0	0,0	0,0	0,0
MPPNB	Abu Hureyra	AH72D 66 F116	6	16	0	1	0	23	26,1	69,6	0,0	4,3	0,0
MPPNB	Abu Hureyra	AH 73 G 48 F85	8	13	0	1	0	22	36,4	59,1	0,0	4,5	0,0
MPPNB	Abu Hureyra	AH 83 F131	3	18	0	0	0	21	14,3	85,7	0,0	0,0	0,0
								Mean	31,6	66,7	0,0	1,8	0,0
Natufian	Hayonim T.	HT 79 P.352 Fig. 3	1	10	9	1	0	21	4,8	47,6	42,9	4,8	0,0
Natufian	Hayonim T.	HT 80 326-10 J32c	0	2	7	9	1	19	0,0	10,5	36,8	47,4	5,3
Natufian	Hayonim T.	HT 80 339-88 J31B	6	1	10	5	2	24	25,0	4,2	41,7	20,8	8,3
Natufian	Hayonim T.	HT 81 353-4 L31b	0	0	5	10	0	15	0,0	0,0	33,3	66,7	0,0
Natufian	Hayonim T.	HT 81 354-15 L31e	0	0	3	18	0	21	0,0	0,0	14,3	85,7	0,0
Natufian	Hayonim T.	HT 81 470-4 K31d	5	4	12	0	0	21	23,8	19,0	57,1	0,0	0,0
Natufian	Hayonim T.	HT 81 C1c 446	0	0	16	5	0	21	0,0	0,0	76,2	23,8	0,0
Natufian	Hayonim T.	HT 81 K31B 427	1	0	15	5	0	21	4,8	0,0	71,4	23,8	0,0
Natufian	Hayonim T.	HT 816 I31C 1412	3	5	2	5	6	21	14,3	23,8	9,5	23,8	28,6
Natufian	Hayonim T.	HT 83 3013	9	2	2	8	0	21	42,9	9,5	9,5	38,1	0,0
Natufian	Hayonim T.	HT 85 1071 27 M 32a	5	4	11	0	1	21	23,8	19,0	52,4	0,0	4,8
Natufian	Hayonim T.	HT 86 1508-1 I32c	1	0	6	8	5	20	5,0	0,0	30,0	40,0	25,0
Natufian	Hayonim T.	HT 86 1665	6	2	8	5	0	21	28,6	9,5	38,1	23,8	0,0

(continued on next page)

Table 8 (continued)

Period	Site	Tool	N					%					
			Ripe	Semi-Ripe	Unripe	Reeds	Grass	Total	Ripe	Semi-Ripe	Unripe	Reeds	Grass
Natufian	Hayonim T.	HT 87 2130 L35a-32	1	9	2	9	0	21	4,8	42,9	9,5	42,9	0,0
Natufian	Hayonim T.	HT 87 I32b 1833-12	4	4	9	2	0	19	21,1	21,1	47,4	10,5	0,0
Natufian	Hayonim T.	HT 89 3189 N74d 505	0	4	6	11	0	21	0,0	19,0	28,6	52,4	0,0
Natufian	Hayonim T.	HT 89 3198 L32a	0	0	3	18	0	21	0,0	0,0	14,3	85,7	0,0
Natufian	Hayonim T.	HT without number	3	2	7	6	2	20	15,0	10,0	35,0	30,0	10,0
								Mean	11,9	13,1	36,0	34,5	4,6
EPPNB	Dja'de	DJ 1024 1.mnt	7	8	0	7	2	24	29,2	33,3	0,0	29,2	8,3
EPPNB	Dja'de	DJ 1027 1.mnt	2	20	1	1	0	24	8,3	83,3	4,2	4,2	0,0
EPPNB	Dja'de	DJ 1031 1.mnt	2	19	2	1	0	24	8,3	79,2	8,3	4,2	0,0
EPPNB	Dja'de	DJ 1040 1.mnt	15	4	0	5	0	24	62,5	16,7	0,0	20,8	0,0
EPPNB	Dja'de	DJ 1043 1.mnt	0	1	3	11	9	24	0,0	4,2	12,5	45,8	37,5
EPPNB	Dja'de	DJ 1069 1.mnt	19	3	0	1	1	24	79,2	12,5	0,0	4,2	4,2
EPPNB	Dja'de	DJ 1079 1.mnt	1	1	0	4	18	24	4,2	4,2	0,0	16,7	75,0
EPPNB	Dja'de	DJ 1094 1.mnt	10	13	0	1	0	24	41,7	54,2	0,0	4,2	0,0
EPPNB	Dja'de	DJ 1207 1.mnt	7	7	0	8	2	24	29,2	29,2	0,0	33,3	8,3
EPPNB	Dja'de	DJ 1281 1.mnt	13	4	1	3	3	24	54,2	16,7	4,2	12,5	12,5
EPPNB	Dja'de	DJ 17 1.mnt	3	16	0	2	2	23	13,0	69,6	0,0	8,7	8,7
EPPNB	Dja'de	DJ 2045 1.mnt	10	10	0	4	0	24	41,7	41,7	0,0	16,7	0,0
EPPNB	Dja'de	DJ 2049 1.mnt	6	13	0	1	4	24	25,0	54,2	0,0	4,2	16,7
EPPNB	Dja'de	DJ 2057 1.mnt	12	5	0	6	1	24	50,0	20,8	0,0	25,0	4,2
EPPNB	Dja'de	DJ 2094 1.mnt	15	4	0	5	0	24	62,5	16,7	0,0	20,8	0,0
EPPNB	Dja'de	DJ 2137 1.mnt	3	11	2	4	4	24	12,5	45,8	8,3	16,7	16,7
EPPNB	Dja'de	DJ 2139 1.mnt	2	13	0	8	1	24	8,3	54,2	0,0	33,3	4,2
EPPNB	Dja'de	DJ 2167 1.mnt	6	15	1	1	1	24	25,0	62,5	4,2	4,2	4,2
EPPNB	Dja'de	DJ 2208 1.mnt	7	7	0	5	1	20	35,0	35,0	0,0	25,0	5,0
EPPNB	Dja'de	DJ 2244 1.mnt	9	8	0	7	0	24	37,5	33,3	0,0	29,2	0,0
EPPNB	Dja'de	DJ 2248 1.mnt	9	5	1	4	5	24	37,5	20,8	4,2	16,7	20,8
EPPNB	Dja'de	DJ 2251 1.mnt	4	1	0	10	8	23	17,4	4,3	0,0	43,5	34,8
EPPNB	Dja'de	DJ 2256 1.mnt	4	14	0	5	1	24	16,7	58,3	0,0	20,8	4,2
EPPNB	Dja'de	DJ 2393 1.mnt	7	10	0	5	2	24	29,2	41,7	0,0	20,8	8,3
EPPNB	Dja'de	DJ 24 1.mnt	1	18	0	3	2	24	4,2	75,0	0,0	12,5	8,3
EPPNB	Dja'de	DJ 244 1.mnt	2	20	1	1	0	24	8,3	83,3	4,2	4,2	0,0
EPPNB	Dja'de	DJ 26 1.mnt	5	4	0	4	11	24	20,8	16,7	0,0	16,7	45,8
EPPNB	Dja'de	DJ 289 1.mnt	8	11	1	2	2	24	33,3	45,8	4,2	8,3	8,3
EPPNB	Dja'de	DJ 293 1.mnt	7	15	0	2	0	24	29,2	62,5	0,0	8,3	0,0
EPPNB	Dja'de	DJ 300 1.mnt	1	2	0	4	17	24	4,2	8,3	0,0	16,7	70,8
EPPNB	Dja'de	DJ 3048 1.mnt	0	0	3	6	15	24	0,0	0,0	12,5	25,0	62,5
EPPNB	Dja'de	DJ 3076 1.mnt	7	5	0	7	5	24	29,2	20,8	0,0	29,2	20,8
EPPNB	Dja'de	DJ 3100 1.mnt	0	14	1	2	6	23	0,0	60,9	4,3	8,7	26,1
EPPNB	Dja'de	DJ 3135 1.mnt	7	2	0	5	10	24	29,2	8,3	0,0	20,8	41,7
EPPNB	Dja'de	DJ 3145 1.mnt	1	15	3	0	5	24	4,2	62,5	12,5	0,0	20,8
EPPNB	Dja'de	DJ 315 1.mnt	0	7	1	2	14	24	0,0	29,2	4,2	8,3	58,3
EPPNB	Dja'de	DJ 3162 1.mnt	10	3	0	10	1	24	41,7	12,5	0,0	41,7	4,2
EPPNB	Dja'de	DJ 3235 1.mnt	9	9	3	3	0	24	37,5	37,5	12,5	12,5	0,0
EPPNB	Dja'de	DJ 3308 1.mnt	1	22	0	1	0	24	4,2	91,7	0,0	4,2	0,0
EPPNB	Dja'de	DJ 3316 1.mnt	15	5	1	3	0	24	62,5	20,8	4,2	12,5	0,0
EPPNB	Dja'de	DJ 354 1.mnt	5	10	1	5	3	24	20,8	41,7	4,2	20,8	12,5
EPPNB	Dja'de	DJ 376 1.mnt	2	18	1	3	0	24	8,3	75,0	4,2	12,5	0,0
EPPNB	Dja'de	DJ 3913 1.mnt	3	16	0	4	1	24	12,5	66,7	0,0	16,7	4,2
EPPNB	Dja'de	DJ 438 1.mnt	4	2	1	9	8	24	16,7	8,3	4,2	37,5	33,3
EPPNB	Dja'de	DJ 5019 1.mnt	4	10	0	1	9	24	16,7	41,7	0,0	4,2	37,5
EPPNB	Dja'de	DJ 8 1.mnt	14	9	0	1	0	24	58,3	37,5	0,0	4,2	0,0
EPPNB	Dja'de	DJ 81 1.mnt	9	0	0	4	11	24	37,5	0,0	0,0	16,7	45,8
EPPNB	Dja'de	DJ 92 1.mnt	17	4	0	3	0	24	70,8	16,7	0,0	12,5	0,0
								Mean	26,6	37,8	2,4	17,0	16,1
MPPNB	Nahal Hemar	NH 2008 756 A	20	4	0	3	0	27	74,1	14,8	0,0	11,1	0,0
MPPNB	Kharaysin	Kh U60 1 E-1A UE318	8	9	0	0	0	17	47,1	52,9	0,0	0,0	0,0
MPPNB	Kharaysin	Kh G100 204	15	3	0	0	0	18	83,3	16,7	0,0	0,0	0,0
MPPNB	Kharaysin	Kh SUP.	18	3	0	0	0	21	85,7	14,3	0,0	0,0	0,0
MPPNB	Kharaysin	Kh U60 1 E 318	16	1	1	1	0	19	84,2	5,3	5,3	5,3	0,0
MPPNB	Kharaysin	Kh UE7 2237	22	2	0	0	0	24	91,7	8,3	0,0	0,0	0,0
MPPNB	Kharaysin	Kh V55 3609	12	8	1	0	0	21	57,1	38,1	4,8	0,0	0,0
MPPNB	Kharaysin	Kh W60 UE314	20	4	0	0	0	24	83,3	16,7	0,0	0,0	0,0
MPPNB	Kharaysin	Kh H100 UE7	23	1	0	0	0	24	95,8	4,2	0,0	0,0	0,0
								Mean	78,5	19,6	1,3	0,7	0,0
EPPNB	Kharaysin	Kh C55 652 2BIS	21	0	1	0	0	22	95,5	0,0	4,5	0,0	0,0
EPPNB	Kharaysin	Kh C55 512	24	4	0	0	0	28	85,7	14,3	0,0	0,0	0,0
EPPNB	Kharaysin	Kh C55 652 1	19	3	1	1	0	24	79,2	12,5	4,2	4,2	0,0
EPPNB	Kharaysin	Kh C55 652 2	0	3	21	4	0	28	0,0	10,7	75,0	14,3	0,0
EPPNB	Kharaysin	Kh E55 551 21996	18	2	1	3	0	24	75,0	8,3	4,2	12,5	0,0
EPPNB	Kharaysin	Kh F55 703 21760 1	23	1	0	0	0	24	95,8	4,2	0,0	0,0	0,0
EPPNB	Kharaysin	Kh F55 703 21760 2	28	0	0	0	0	28	100,0	0,0	0,0	0,0	0,0
								Mean	75,9	7,1	12,6	4,4	0,0
PPNA	Kharaysin	Kh 2018 B50 1	2	14	0	8	0	24	8,3	58,3	0,0	33,3	0,0

(continued on next page)

Table 8 (continued)

Period	Site	Tool	N					%					
			Ripe	Semi-Ripe	Unripe	Reeds	Grass	Total	Ripe	Semi-Ripe	Unripe	Reeds	Grass
PPNA	Kharaysin	Kh 2018 C55 1	8	9	0	6	1	24	33,3	37,5	0,0	25,0	4,2
PPNA	Kharaysin	Kh 2018 D50 1	4	9	0	6	5	24	16,7	37,5	0,0	25,0	20,8
								Mean	19,4	44,4	0,0	27,8	8,3
LPPNA	Jerf el Ahmar	JF 25 23 3-1	21	3	0	0	0	24	87,5	12,5	0,0	0,0	0,0
LPPNA	Jerf el Ahmar	JF A7918-1	14	10	0	0	0	24	58,3	41,7	0,0	0,0	0,0
LPPNA	Jerf el Ahmar	JF B25 2-1	6	18	0	0	0	24	25,0	75,0	0,0	0,0	0,0
LPPNA	Jerf el Ahmar	JF B83 2-1	16	7	1	0	0	24	66,7	29,2	4,2	0,0	0,0
LPPNA	Jerf el Ahmar	JF C 281-1	11	11	2	0	0	24	45,8	45,8	8,3	0,0	0,0
LPPNA	Jerf el Ahmar	JF E17 35-1	0	8	16	0	0	24	0,0	33,3	66,7	0,0	0,0
LPPNA	Jerf el Ahmar	JF E1825-1	2	9	8	0	0	19	10,5	47,4	42,1	0,0	0,0
LPPNA	Jerf el Ahmar	JF E84 4-1	7	1	9	4	0	21	33,3	4,8	42,9	19,0	0,0
LPPNA	Jerf el Ahmar	JF F30 10-1	6	19	0	0	0	25	24,0	76,0	0,0	0,0	0,0
LPPNA	Jerf el Ahmar	JF H81 6A-1	20	4	0	0	0	24	83,3	16,7	0,0	0,0	0,0
LPPNA	Jerf el Ahmar	JF H81 6B-1	15	8	0	0	0	23	65,2	34,8	0,0	0,0	0,0
LPPNA	Jerf el Ahmar	JF ZV 21 14-1	13	7	0	0	0	20	65,0	35,0	0,0	0,0	0,0
LPPNA	Jerf el Ahmar	JF ZV 21 3-1	13	3	6	0	1	23	56,5	13,0	26,1	0,0	4,3
LPPNA	Jerf el Ahmar	JF ZW 25 1-1	4	1	9	1	0	15	26,7	6,7	60,0	6,7	0,0
LPPNA	Jerf el Ahmar	JF ZW 25 2-1	7	3	12	2	0	24	29,2	12,5	50,0	8,3	0,0
								Mean	45,1	32,3	20,0	2,3	0,3
LPPNB	Ba'ja	B 22242 C20-62 A1	14	9	0	1	0	24	58,3	37,5	0,0	4,2	0,0
LPPNB	Ba'ja	B92073 C22-R6-12 A1	4	18	1	1	0	24	16,7	75,0	4,2	4,2	0,0
								Mean	37,5	56,3	2,1	4,2	0,0
EPPNB	T. Qarassa N	TQN 14 53 A 3-	1	17	4	1	0	23	4,3	73,9	17,4	4,3	0,0
EPPNB	T. Qarassa N	TQN V17 14 1	10	4	7	1	0	22	45,5	18,2	31,8	4,5	0,0
EPPNB	T. Qarassa N	TQN V17 14 2	22	0	0	0	0	22	100,0	0,0	0,0	0,0	0,0
EPPNB	T. Qarassa N	TQN V67 1 4	22	1	0	0	0	23	95,7	4,3	0,0	0,0	0,0
EPPNB	T. Qarassa N	TQN V67 10 1	10	9	7	0	0	26	38,5	34,6	26,9	0,0	0,0
EPPNB	T. Qarassa N	TQN V67 10	20	1	4	1	0	26	76,9	3,8	15,4	3,8	0,0
EPPNB	T. Qarassa N	TQN V67 14 245	18	7	1	0	0	26	69,2	26,9	3,8	0,0	0,0
EPPNB	T. Qarassa N	TQN V67 15 270	4	7	7	1	0	19	21,1	36,8	36,8	5,3	0,0
EPPNB	T. Qarassa N	TQN V67 2285	1	12	7	0	0	20	5,0	60,0	35,0	0,0	0,0
EPPNB	T. Qarassa N	TQN V67 2289	16	1	1	1	0	19	84,2	5,3	5,3	5,3	0,0
EPPNB	T. Qarassa N	TQN V67 3 23	21	1	1	0	0	23	91,3	4,3	4,3	0,0	0,0
EPPNB	T. Qarassa N	TQN V67 4 1	11	7	2	2	0	22	50,0	31,8	9,1	9,1	0,0
EPPNB	T. Qarassa N	TQN V67 4135	11	8	3	0	0	22	50,0	36,4	13,6	0,0	0,0
EPPNB	T. Qarassa N	TQN V67 4 2	14	6	0	0	0	20	70,0	30,0	0,0	0,0	0,0
EPPNB	T. Qarassa N	TQN Y67 24 62	12	4	10	1	0	27	44,4	14,8	37,0	3,7	0,0
EPPNB	T. Qarassa N	TQN Y67 24 C4D 2	14	6	3	1	0	24	58,3	25,0	12,5	4,2	0,0
EPPNB	T. Qarassa N	TQN Y67 24 C4D1	13	1	0	0	0	14	92,9	7,1	0,0	0,0	0,0
EPPNB	T. Qarassa N	TQN Y67 29 107 1-	12	3	9	0	0	24	50,0	12,5	37,5	0,0	0,0
EPPNB	T. Qarassa N	TQN Y67 6300	30	3	0	2	0	35	85,7	8,6	0,0	5,7	0,0
EPPNB	T. Qarassa N	TQN Y67 A1 25 11294	23	1	0	0	0	24	95,8	4,2	0,0	0,0	0,0
EPPNB	T. Qarassa N	TQN Y67 E1 25	17	4	2	1	0	24	70,8	16,7	8,3	4,2	0,0
EPPNB	T. Qarassa N	TQN Y67 E2 24	21	5	7	1	0	34	61,8	14,7	20,6	2,9	0,0
EPPNB	T. Qarassa N	TQN Y67 E2 25 11285 A	0	0	7	10	0	17	0,0	0,0	41,2	58,8	0,0
EPPNB	T. Qarassa N	TQN Y67 E2 25 11285 B	0	12	14	2	0	28	0,0	42,9	50,0	7,1	0,0
EPPNB	T. Qarassa N	TQN Y67 E2 25 11287	10	3	6	1	0	20	50,0	15,0	30,0	5,0	0,0
EPPNB	T. Qarassa N	TQN Y67 E8 25 11078 A	21	0	1	1	0	23	91,3	0,0	4,3	4,3	0,0
EPPNB	T. Qarassa N	TQN Y67 E8 25 11078 B	6	13	2	3	0	24	25,0	54,2	8,3	12,5	0,0
EPPNB	T. Qarassa N	TQN Y68 1	22	1	1	0	0	24	91,7	4,2	4,2	0,0	0,0
EPPNB	T. Qarassa N	TQN Y68 21	24	0	0	0	0	24	100,0	0,0	0,0	0,0	0,0
EPPNB	T. Qarassa N	TQN Y68 24	1	1	14	4	2	22	4,5	4,5	63,6	18,2	9,1
EPPNB	T. Qarassa N	TQN Y68 24 199	17	6	1	0	0	24	70,8	25,0	4,2	0,0	0,0
EPPNB	T. Qarassa N	TQN Y68 29 132	23	2	0	2	0	27	85,2	7,4	0,0	7,4	0,0
EPPNB	T. Qarassa N	TQN Y68 29 B	14	5	1	3	0	23	60,9	21,7	4,3	13,0	0,0
EPPNB	T. Qarassa N	TQN Y68 52C 11159	24	0	0	0	0	24	100,0	0,0	0,0	0,0	0,0
EPPNB	T. Qarassa N	TQN Y68 A1 24	9	5	7	1	2	24	37,5	20,8	29,2	4,2	8,3
EPPNB	T. Qarassa N	TQN Y68 A2 25 258	23	1	0	0	0	24	95,8	4,2	0,0	0,0	0,0
EPPNB	T. Qarassa N	TQN Y68 A3 24 B	13	9	2	0	0	24	54,2	37,5	8,3	0,0	0,0
EPPNB	T. Qarassa N	TQN Y68 B3 40 120	24	0	0	0	0	24	100,0	0,0	0,0	0,0	0,0
EPPNB	T. Qarassa N	TQN Y68 C3 11251	17	7	0	0	0	24	70,8	29,2	0,0	0,0	0,0
EPPNB	T. Qarassa N	TQN Y68 C3 52 11198	12	9	3	0	0	24	50,0	37,5	12,5	0,0	0,0
EPPNB	T. Qarassa N	TQN Y68 C3 52 11210	28	0	0	0	0	28	100,0	0,0	0,0	0,0	0,0
EPPNB	T. Qarassa N	TQN Y68 C5 52	3	14	4	1	0	22	13,6	63,6	18,2	4,5	0,0
EPPNB	T. Qarassa N	TQN Y68 C5 52 B 11134	28	0	0	0	0	28	100,0	0,0	0,0	0,0	0,0
EPPNB	T. Qarassa N	TQN Y68 C5 52C 11133	3	18	1	0	0	22	13,6	81,8	4,5	0,0	0,0
EPPNB	T. Qarassa N	TQN Y68 D4 52 11262	8	0	11	3	2	24	33,3	0,0	45,8	12,5	8,3
EPPNB	T. Qarassa N	TQN Y68 DE-45 27	23	1	0	0	0	24	95,8	4,2	0,0	0,0	0,0
EPPNB	T. Qarassa N	TQN Y68 E3 14 1	16	4	3	1	0	24	66,7	16,7	12,5	4,2	0,0
EPPNB	T. Qarassa N	TQN Y68 E3 14 2	22	1	0	0	1	24	91,7	4,2	0,0	0,0	4,2
EPPNB	T. Qarassa N	TQN Y68 E3 14	20	0	3	0	5	28	71,4	0,0	10,7	0,0	17,9
EPPNB	T. Qarassa N	TQN Y69 C4 52 A	2	9	13	0	0	24	8,3	37,5	54,2	0,0	0,0
EPPNB	T. Qarassa N	TQN Y69 C4 52 B	4	3	15	2	0	24	16,7	12,5	62,5	8,3	0,0
								Mean	60,0	19,5	15,4	4,2	0,9

(continued on next page)

Table 8 (continued)

Period	Site	Tool	N					%					
			Ripe	Semi-Ripe	Unripe	Reeds	Grass	Total	Ripe	Semi-Ripe	Unripe	Reeds	Grass
Natufian	Shubayqa 1	CM004 Sh1	0	15	0	8	5	28	0	53,6	0	28,6	17,9
Natufian	Shubayqa 1	CM005 Sh1	0	8	0	13	6	27	0	29,6	0	48,1	22,2
Natufian	Shubayqa 1	CM006 Sh1	0	4	0	7	13	24	0	16,7	0	29,2	54,2
Natufian	Shubayqa 1	CM007 Sh1	0	3	0	15	5	23	0	13,0	0	65,2	21,7
Natufian	Shubayqa 6	CM031 Sh6	0	4	0	8	11	23	0,0	17,4	0,0	34,8	47,8
Natufian	Shubayqa 6	CM0023 Sh6	0	12	0	8	9	29	0,0	41,4	0,0	27,6	31,0
								Mean	0	28,6	0	38,9	32,5
PPNA	Shubayqa 6	CM008 Sh6 A-1A	0	8	0	1	3	12	0,0	66,7	0,0	8,3	25,0
PPNA	Shubayqa 6	CM015 Sh6 A-1A	6	14	0	5	1	26	23,1	53,8	0,0	19,2	3,8
PPNA	Shubayqa 6	CM017 Sh6 A-1A	0	4	0	5	6	15	0,0	26,7	0,0	33,3	40,0
PPNA	Shubayqa 6	CM079 Sh6 A-1A	5	6	0	10	1	22	22,7	27,3	0,0	45,5	4,5
								Mean	11,4	43,6	0,0	26,6	18,3

Table 9

Summary of the classification of archaeological tools by site/level. Numbers represent individual sickle blades.

SITE	PERIOD	CHRONOLOGY	REGION	Ripe cereal	Semi-ripe cereal	Unripe cereal	Reeds	Grass	Indeterminate	Total
Hayonim Terrace	Natufian	11 700–11,200	S. Levant					4	10	18
Shubayqa 1	Natufian	12 400–11,100 BC	S. Levant		1		1	1	1	4
Shubayqa 6	Natufian	10 300–9800 BC	S. Levant						2	2
Shubayqa 6	EPPNA	9900–9200 BC	S. Levant		2				2	4
Kharaysin	PPNA	9100–8700 BC	S. Levant		1				2	3
Tell Qarassa North	EPPNB	8500–8200 BC	S. Levant	30	5		1		10	49
Kharaysin	EPPNB	8400–8250 BC	S. Levant	6		1				7
Kharaysin	MPPNB	8000–7600 BC	S. Levant	7	1					8
Nahal Hemar	MPPNB	7700–7100 l BC	S. Levant	1						1
Ba'ja	LPPNB	7500–6900 l BC	S. Levant	1	1					2
Abu Hureyra	Natufian	11 200–10,700 BC	M. Euphrates		1				3	4
Tell Mureybet	Natufian	10 400–10,000 BC	M. Euphrates		2				1	3
Tell Mureybet	PPNA	9600–8700 BC	M. Euphrates	3	2	3	1		4	13
Jer el Ahmar	LPPNA	8800–8600 BC	M. Euphrates	7	2	2			4	15
Tell Mureybet	EPPNB	8600–8300 BC	M. Euphrates	3	3	1			3	10
Dja'de el Mughara	EPPNB	8540–8290 BC	M. Euphrates	7	16	0		4	21	48
Abu Hureyra	MPPNB	7700–7400 BC	M. Euphrates	1	4					5
Tell Halula	MPPNB	7700–7400 BC	M. Euphrates	5					4	9
Tell Halula	LPPNB	7300–7000 BC	M. Euphrates	5	4				1	10

Table 10

Classification of % of 3D samples of gloss by texture analysis of tools found in archaeological sites/levels of Southern Levant.

	Ripe	Semi-ripe	Unripe	Reeds	Grass
Hayonim Terrace Natufian	11,9	13,1	36,0	34,5	4,6
Shubayqa 1 and 6 Natufian	0	28,6	0	38,9	32,5
Shubayqa 6 EPPNA	11,4	43,6	0,0	26,6	18,3
Kharaysin PPNA	19,4	44,4	0,0	27,8	8,3
TQN EPPNB	60,0	19,5	15,4	4,2	0,9
Kharaysin EPPNB	75,9	7,1	12,6	4,4	0,0
Kharaysin MPPNB	78,5	19,6	1,3	0,7	0,0
Nahal Hemar MPPNB	74,1	14,8	0,0	11,1	0,0
Ba'ja LPPNB	37,5	56,3	2,1	4,2	0,0

Table 11

Classification of % of 3D samples of gloss by texture analysis of tools found in archaeological sites/levels of The Middle Euphrates.

	Ripe	Semi-ripe	Unripe	Reeds	Grass
AH/Mb Natufian	13,1	51,2	22,2	10,4	3,0
Mureybet PPNA	29,6	36,3	20,6	12,4	1,2
Jerf PPNA	45,1	32,3	20,0	2,3	0,3
Mureybet EPPNB	36,9	42,7	13,9	3,4	3,1
Dja'de EPPNB	26,6	37,8	2,4	17,0	16,1
Abu Hureyra MPPNB	31,6	66,7	0,0	1,8	0,0
Halula MPPNB	50,3	29,2	12,6	7,3	0,7
Halula LPPNB	48,8	41,2	5,5	4,5	0,0

3. Results

3.1. Analytical results

215 archaeological tools recovered in 19 occupation phases at 12 archaeological sites located in the Middle Euphrates (Northern Levant) and Southern Levant dating from the 13th to the late 8th millennium cal BC were analyzed in this study. Glossed tools from Tell Halula (Late and Middle PPNB), Mureybet (Early PPNB, PPNA and Natufian), Abu Hureyra (Natufian) and Hayonim Terrace (Natufian) were already studied in [Ibáñez et al. \(2016\)](#), Djade (Early PPNB) in [Pichon et al. \(2021\)](#) and Nahal Hemar (Middle PPNB) in [Borrell et al. \(2020\)](#). Glossed tools from Abu Hureyra (Middle PPNB), Kharaysin (Middle PPNB, Early PPNB and Late PPNA), Jerf el Ahmar (Late PPNA), Tell Qarassa North (Early PPNB), Shubayqa 1 (Natufian) and Shubayqa 6 (Natufian and PPNA) have been analyzed for the first time with confocal microscopy in this study.

The results of the analysis are first listed according to the classification of individual tools. As explained above, we measured around 21 surface samples from each tool. For this classification, when more than 50% of the surface samples are classified in any of the five plant cutting groups, the tool is identified as belonging to this group. If fewer than 50% of the surface samples are classified in the plant cutting groups, the tool is considered as indeterminate. The classification of each tool is shown in [Table 8](#) while the summary of the results by site/level is shown in [Table 9](#).

The results are also listed considering the proportion of all the surface samples classified in the five plant cutting groups for each

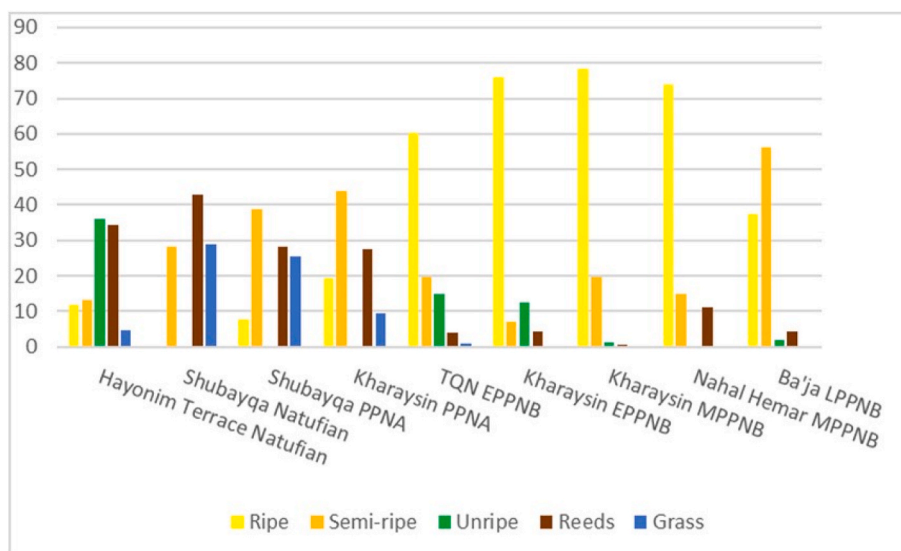


Fig. 11. Classification of % of 3D samples of gloss on the five categories of plant-cutting tools from archaeological sites in Southern Levant.

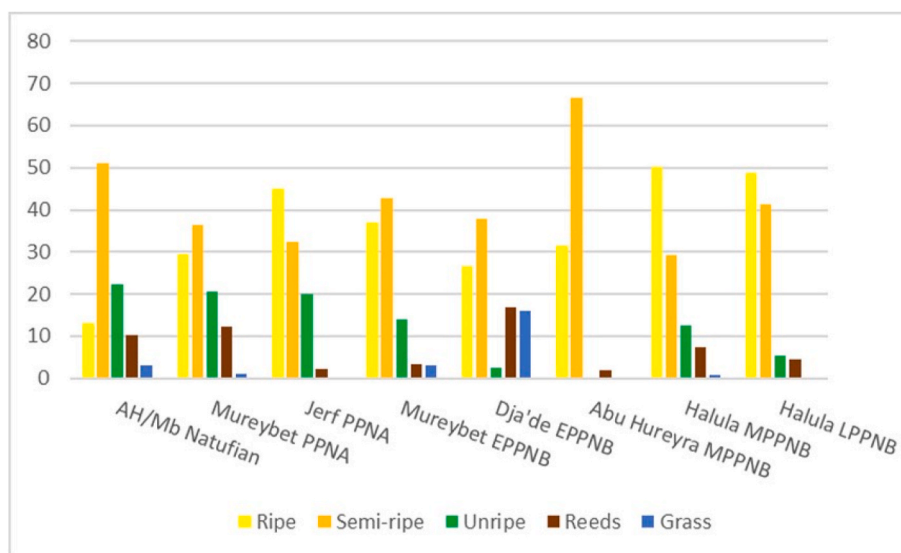


Fig. 12. Classification of % of 3D samples of gloss on the five categories of plant-cutting tools from sites in The Middle Euphrates.

Table 12

Index of the degree of maturity of cereals harvested with lithic tools based on texture analysis of gloss for sites in The Middle Euphrates. It is calculated considering exclusively the results attributed to cereal harvesting in the three stages of maturity. The proportion of unripe harvesting was multiplied by three, semi-ripe harvesting by two and ripe harvesting by one and the addition was calculated. Thus, 300 would be the index of a site with exclusive unripe cutting and 100 of one with exclusive ripe cutting.

Period	Site	Index
LPPNB	Tell Halula	155
MPPNB	Tell Halula	160
MPPNB	Abu Hureyra	168
EPPNB	Dja'de	164
EPPNB	Tell Mureybet	175
LPPNA	Jerf el Ahmar	174
PPNA	Tell Mureybet	190
Natufian	Abu Hureyra	210

Table 13

Index of the degree of maturity of cereals harvested with lithic tools based on texture analysis of gloss for sites in Southern Levant. It is calculated considering exclusively the results attributed to cereal harvesting in the three stages of maturity. The proportion of unripe harvesting was multiplied by three, semi-ripe harvesting by two and ripe harvesting by one and the addition was calculated. Thus, 300 would be the index of a site with exclusive unripe cutting and 100 of one with exclusive ripe cutting.

Period	Site	Index
MPPNB	Kharaysin	122
EPPNB	Kharaysin	134
EPPNB	Tell Qarassa Norte	152
PPNA	Kharaysin	170
PPNA	Shubayqa 6	179
Natufian	Shubayqa 1/6	200
Natufian	Hayonim Terrace	239

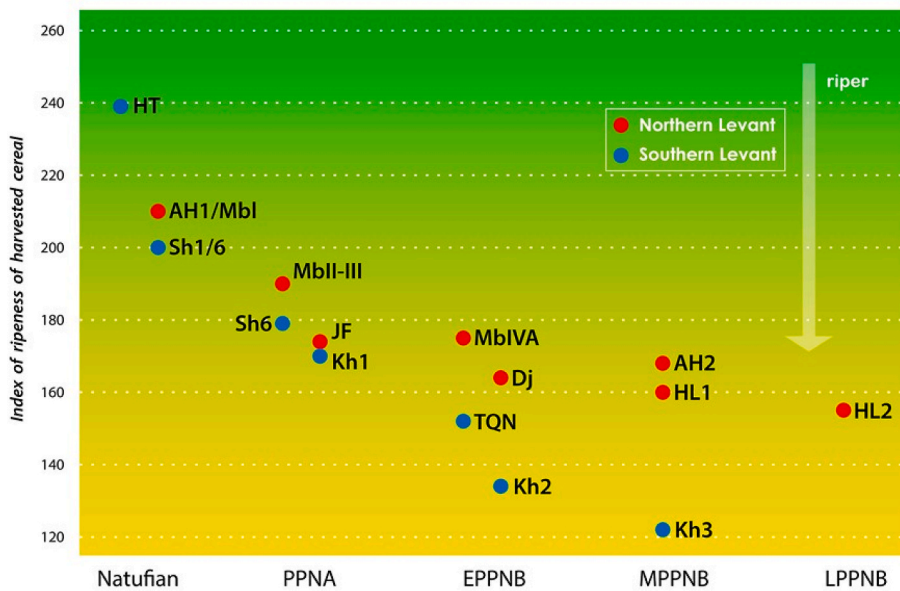


Fig. 13. Change in the index of the degree of maturity of harvested cereals in Southern and The Middle Euphrates. HT: Hayonim Terrace. AH1/Mbl: Abu Hureyra and Tell Mureybet (Natufian); Sh1/6: Shubayqa 1 and 6 (Natufian); Sh6: Shubayqa 6 (PPNA); JF: Jerf el Ahmar (PPNA); Kh1: Kharaysin (PPNA); MbIVA: Tell Mureybet (EPPNB); TQN: Tell Qarassa North (EPPNB); Dj: Dja' de el Mughara (EPPNB); Kh2: Kharaysin (EPPNB); HL1: Tell Halula (MPPNB); Kh3: Kharaysin (MPPNB); HL2: Tell Halula (LPPNB).

archaeological context. As each tool is characterized by slightly different quantities of surface images, for this calculation we plot the proportion of samples classified in each plant working group by site/level. The result for each archaeological context is derived from the average of all the glossed tools studied in each context.

The results are listed in Table 10 and Fig. 11 for the Southern Levant sites and in Table 11 and Fig. 12 for The Middle Euphrates. Thus, data about the classification of individual tools (Table 9) and for the 3D surfaces for each site/level (Tables 10 and 11 and Figs. 12 and 13) are complementary and they do not plot exactly the same information.

As a third way to plot our results, an index of the degree of maturity of harvested cereals (Tables 12 and 13 and Fig. 13) was calculated for the sites/levels in the Northern and Southern Levant (for the procedure, see section 2.4). The tendency to harvest riper cereals through time can be observed in both regions. However, some differences appear, as harvesting in the South is consistently at a riper stage than in the North, especially from the Early PPNB period (circa 8500 cal BC).

3.2. Change in plant harvesting techniques in the Southern Levant

In the Southern Levant, the sickles from the Natufian site of Hayonim Terrace analyzed for this study indicate both harvesting of unripe cereals, as well as reed cutting during the 12th millennium cal BC. Unripe cereal harvesting stands out among the tools used for cereal cutting (Fig. 14), though reed cutting is also relevant (Fig. 15). The archaeobotanical analysis identified wild barley (*Hordeum spontaneum*) among the archaeobotanical macro-remain assemblage (Buxó, 1992), while phytolith analysis showed the existence of remains of seed husks from mostly wild wheat and abundant wild barley, as well as phytoliths from stems of cereals/grasses, reeds and rushes (Rosen, 1992). The combination of archaeobotanical and use-wear lines of evidence suggests that wild uncultivated cereals were harvested at the site. The gloss texture analysis from Shubayqa 1 and 6 (Natufian) indicates a variety of plant-cutting activities, including the cutting of semi-ripe cereals, reeds and other grasses (Fig. 16). The initial analysis of the Shubayqa 1 archaeobotanical assemblage suggests that cereals were rarely exploited by its inhabitants, whereas Cyperaceae tubers dominated the assemblage (Arranz-Otaegui et al., 2018). This corresponds to the rarity of

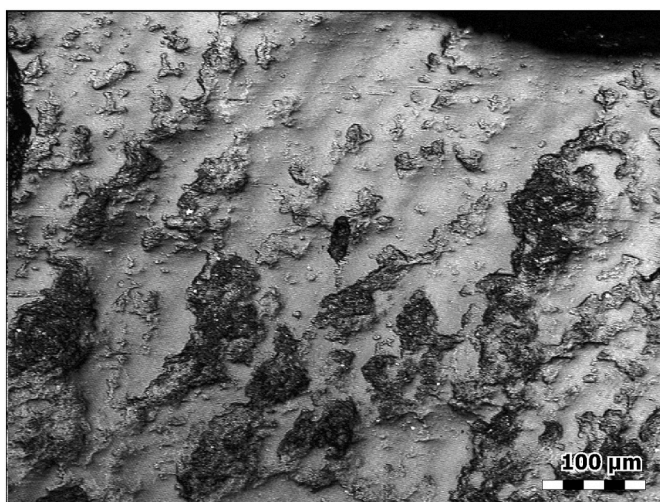


Fig. 14. Usewear polish from tool HT 81 K31B 427 2 (Hayonim Terrace, Natufian) classified as green cereal harvesting.

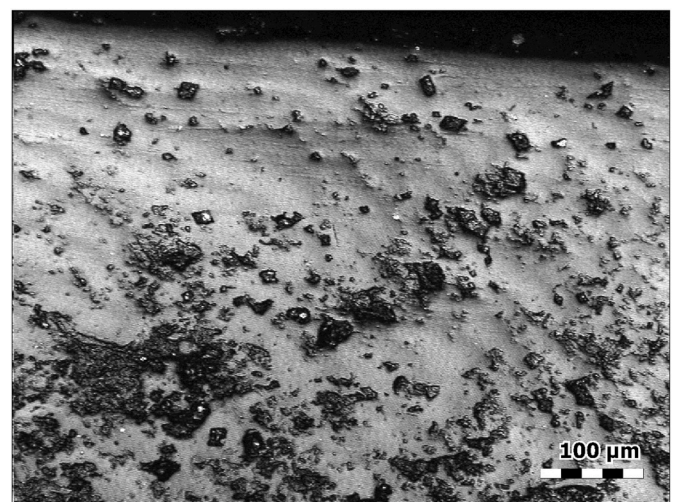


Fig. 15. HT 81 354-15 L31e (Hayonim Terrace, Natufian) classified as reed harvesting.

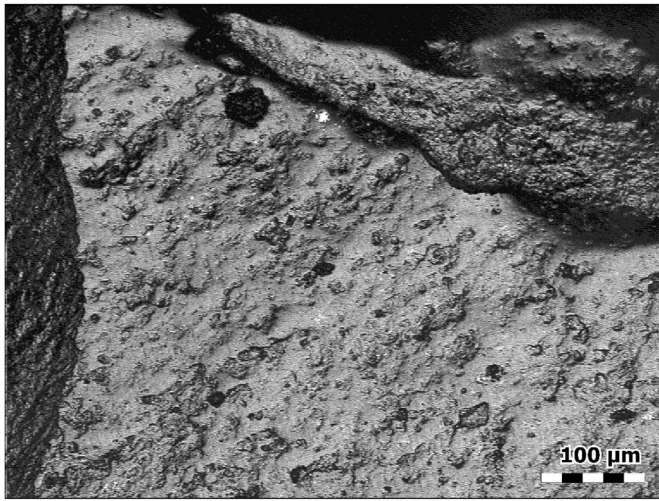


Fig. 16. CM 006 Sh1 (Shubayqa 1, Natufian), classified as grass-harvesting.

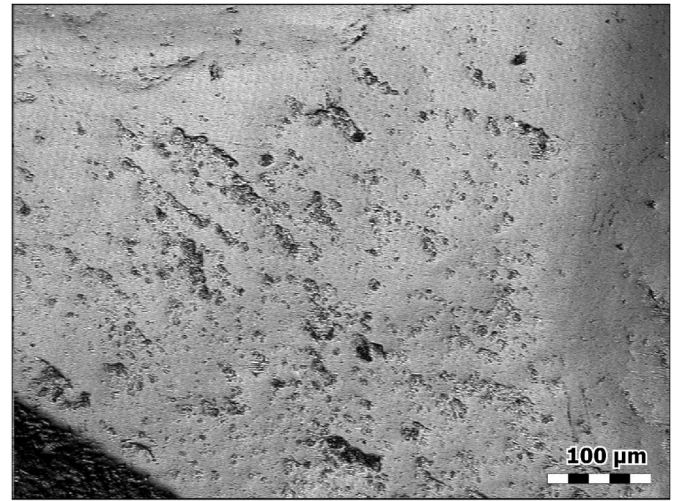


Fig. 18. TQN Y67 24 C4D1 (Tell Qarassa North, EPPNB), classified as ripe cereal harvesting.

sickle flint tools in the lithic assemblage, although there are many ground stone artefacts at the site (Pedersen et al., 2016). Wild cereals and club-rush tubers were used to produce flat bread-like products (Arranz-Otaegui et al., 2018). In these Natufian sites, gloss texture analysis shows a variety of plant-cutting activities (cereals, reeds and other grass), while the importance of unripe harvesting suggests the exploitation of wild cereals in natural stands in Hayonim Terrace.

The data from Shubayqa 6 and Kharaysin 1 (PPNA) indicate cutting of semi-ripe cereals (Fig. 17). This could potentially be interpreted as evidence for harvesting cultivated wild cereals, which fits the archaeobotanical information indicating wild cereal cultivation during this period in the Levant (Arranz-Otaegui et al., 2016). Nevertheless, only a small number of tools from these sites were analyzed and the archaeobotanical study of both sites has not been completed yet so this conclusion has to be considered preliminary. Like with Shubayqa 1, sickle blades are rare in the Shubayqa 6 lithic assemblage, although there are many ground stone artefacts at the site. Further analysis of additional sickles from these and other Natufian and PPNA sites in the southern Levant are necessary to interpret the evidence obtained.

Dominant ripe cereal-harvesting appears for the first time in the Early PPNB levels of Tell Qarassa North (TQN) around cal 8500 cal BC (Figs. 18–20). The cereal assemblage from Tell Qarassa North comprises wild and domesticated-type species of emmer wheat (*T. dicoccoides*/

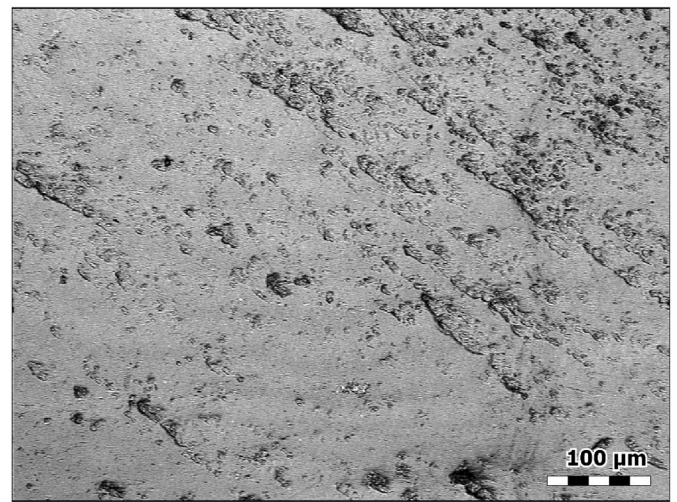


Fig. 19. TQN V17 14 2 (Tell Qarassa North, EPPNB), classified as ripe cereal harvesting.

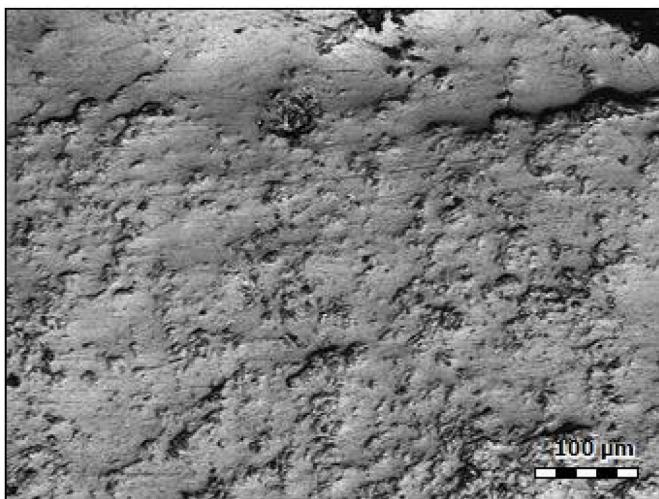


Fig. 17. CM015 Sh 6 (Shubayqa 6, PPNA), classified as semi-ripe cereal harvesting.

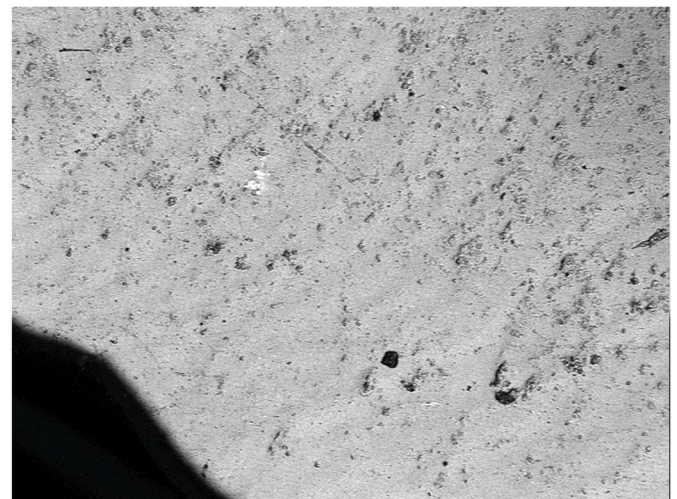


Fig. 20. TQN 14 53 (Tell Qarassa North, EPPNB), classified as semi-ripe cereal harvesting.

dicoccum), one- and two-grained einkorn wheat (*T. boeoticum/monococcum/urartu*), and barley (*Hordeum spontaneum/vulgare*). Domesticated-type scars were identified on the emmer, einkorn, and barley chaff at a frequency higher than expected in wild cereal species (21.1–41.2%). Based on these results it can be concluded that by 8700–8200 cal BC there are positive signs that barley, emmer and einkorn were being cultivated and partially domesticated at Tell Qarassa North (Arranz-Otaegui et al., 2016). In the contemporaneous levels of Tell Aswad, emmer and barley were exploited and the latter also shows high proportions of domestic type spikelets (30%) (Tanno and Willcox, 2012; Douché and Willcox, 2018). In Tell Qarassa North, gloss texture analysis finds higher proportions of ripe harvesting than would correspond to a context where fully domesticated cereals only reach 30–40% (see also below).

Ripe cereal harvesting continues to dominate in the slightly later Early PPNB levels of Kharaysin (8400–8100 cal BC) (Fig. 21), in the Middle PPNB levels of the same site (8000–7700 BC) (Fig. 22) and for one sickle from Nahal Hemar (Borrell et al., 2020), while in the Late PPNB levels at Ba'ja ripe cereal cutting decreases and semi-ripe cutting stands out slightly. Thus, ripe harvesting starts to become dominant in the Southern Levant from the Early PPNB, which fits well with the presence of domestic varieties of cereals from that period observed in archaeobotanical assemblages (Tanno and Willcox, 2012). Unripe cereal cutting is marginal in the period in which ripe cereal harvesting dominates (mid 9th to mid-8th millennium BC), though it is still present in the EPPNB at Tell Qarassa North and Kharaysin.

Reed cutting is observed in the older periods/sites, such as Hayonim Terrace, Shubayqa 1 and 6 and Kharaysin PPNA. However, from the Early PPNB onward reed cutting is very marginal. Reed cutting, an activity likely related to the making of baskets, matting or for roofing houses, is more easily detected in contexts in which cereal harvesting was not very prevalent. However, when cereal harvesting became dominant among plant-cutting activities, from the EPPNB onwards, other plant-cutting tools likely decreased proportionally in comparison to cereal-cutting tools.

3.3. Change in plant harvesting techniques in the Middle Euphrates

In the Middle Euphrates, the sickle blades from the Late Natufian at Abu Hureyra and Mureybet show use-wear patterns matching the experimental sickles used to cut both semi-ripe and unripe cereals. The presence of sickles showing evidence for cutting unripe cereals is not surprising considering that if wild cereals were harvested, cutting them

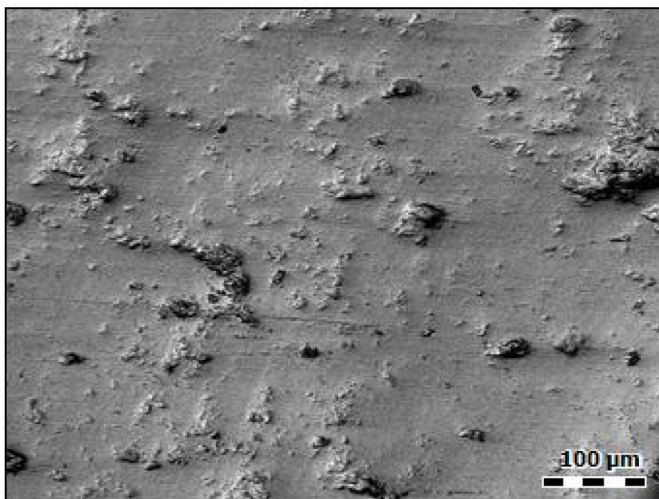


Fig. 21. Kh E55 551 21996 (Kharaysin, EPPNB), classified as ripe cereal harvesting.

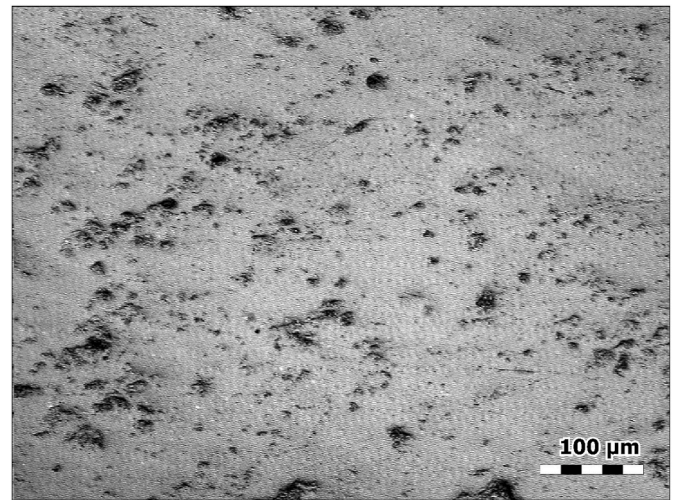


Fig. 22. Kh UE7 2237 (Kharaysin, MPPNB), classified as ripe cereal harvesting.

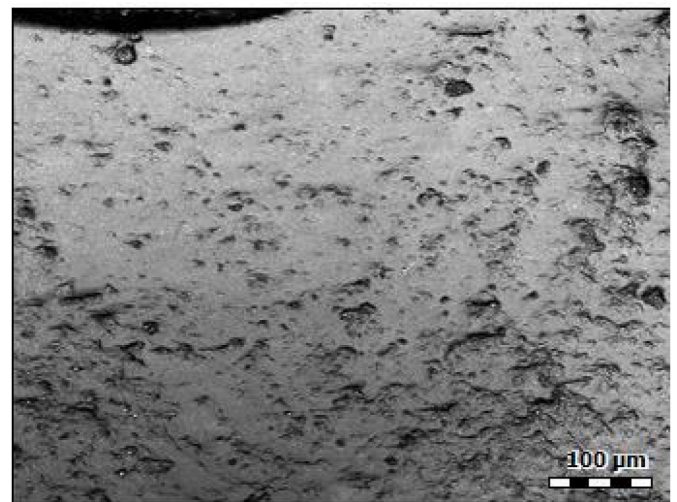


Fig. 23. AH PA 21 (Abu Hureyra, Natufian), classified as semi-ripe cereal harvesting.

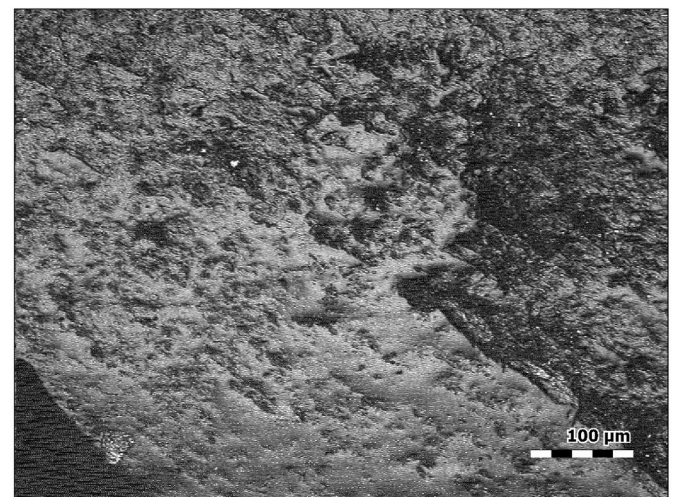


Fig. 24. Mb 73 6430 (Tell Mureybet, EpiNatufian), classified as semi-ripe cereal harvesting.

green would be most advantageous to obtain the maximum yield. However, it is interesting to highlight the presence of sickle blades that, based on texture parameters, coincide with those that were used to harvest cultivated wild cereals in our experiments (Figs. 23 and 24). Whether Natufian groups were cultivating wild cereal stands has been a matter of discussion since the 1950s (Henry, 1989; Hillman, 2000; Bar-Yosef, 2011). To date, there is no clear empirical archaeobotanical data that supports this possibility (Colledge and Conolly, 2010; Willcox, 2012). In fact, the proportion of cereals among other plant resources in the archaeobotanical record of Abu Hureyra 1 and Mureybet I is small (Hillman, 2000; van Zeist and Bakker-Heeres, 1984). Taken together, our results could suggest that Natufian groups at these sites were exploiting both wild cereal stands and, perhaps, managed fields, where cereals were growing in denser stands and could therefore be optimized for harvesting in a semi-ripe stage. Further archaeobotanical and gloss texture analysis is needed to verify this hypothesis.

From the end of the 10th to the end of the 9th millennium cal BC, ripe, semi-ripe and unripe harvesting are present at Mureybet III (PPNA), Jerf el Ahmar (Late PPNA), Mureybet IVA (Early PPNB) and Dja'de el Mughara (Early PPNB). In all these contexts, archaeobotanical evidence shows large-scale exploitation and cultivation of morphologically wild cereals (Colledge, 1998; Willcox et al., 2008; Willcox and Stordeur, 2012; Pichon et al., 2021; Douché and Willcox, 2018). The prevalence of semi-ripe harvesting (Figs. 25–29) in these sites/levels (dominant in Mureybet III and IV and in Dja'de) fits well with the cultivation of wild cereals (Pichon et al., 2021). The identification of unripe cereal cutting (Figs. 30 and 31), especially in the PPNA levels of Mureybet III and Jerf el Ahmar, suggests that spontaneous wild cereals were also exploited. Unripe cereal cutting tends to diminish through time and it is marginal or inexistent in the PPNB contexts/sites (Mureybet IVA, Dja'de, Abu Hureyra and Halula). Sickle gloss texture analysis also indicates that ripe harvesting was common in these contexts (Figs. 32–36) even though domestic cereals were not present. The appearance of relevant proportions of ripe harvesting before domestic varieties were dominant is also observed in the Early PPNB levels of Tell Qarassa North, in the southern Levant. It is necessary to bear in mind that our classificatory method tends to wrongly identify some tools used with semi-ripe/wild cultivated cereals as resulting from ripe/domestic cereal harvesting (21% misclassification; see Methodology). Thus, there could be a bias to wrongly identify some glossed surfaces in tools of semi-ripe cereal cutting as resulting from ripe harvesting. However, the identification of considerable proportions of ripe harvesting seems to indicate that some cereals were harvested in an advanced state of maturity. This could suggest that before the

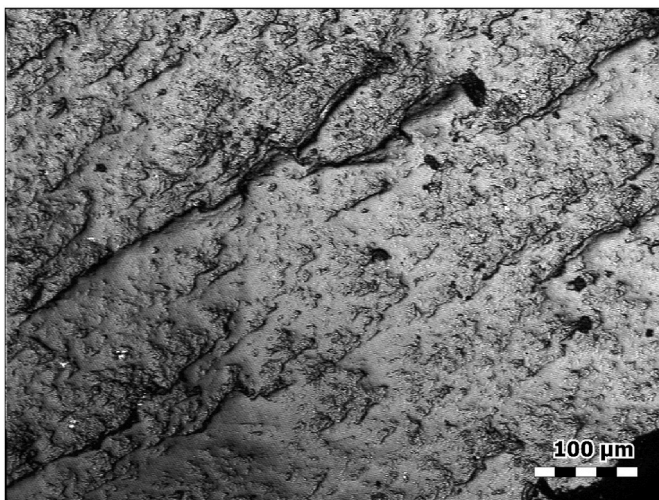


Fig. 25. Mb 74 1384 (Tell Mureybet, PPNA), classified as semi-ripe cereal harvesting.

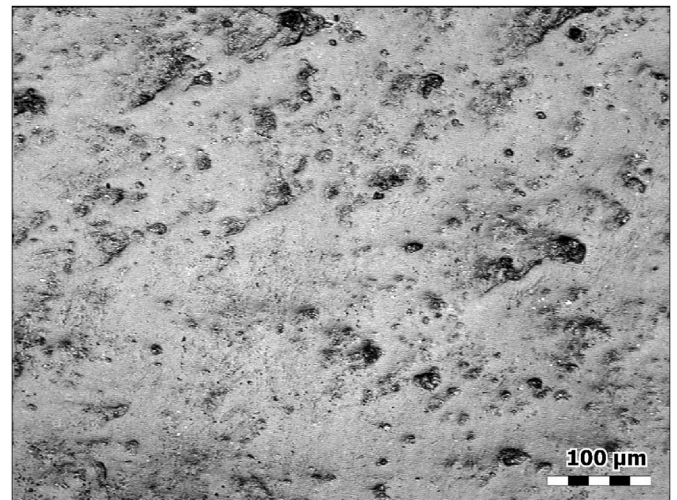


Fig. 26. JF F30 10 (Jerf el Ahmar, PPNA), classified as semi-ripe cereal harvesting.

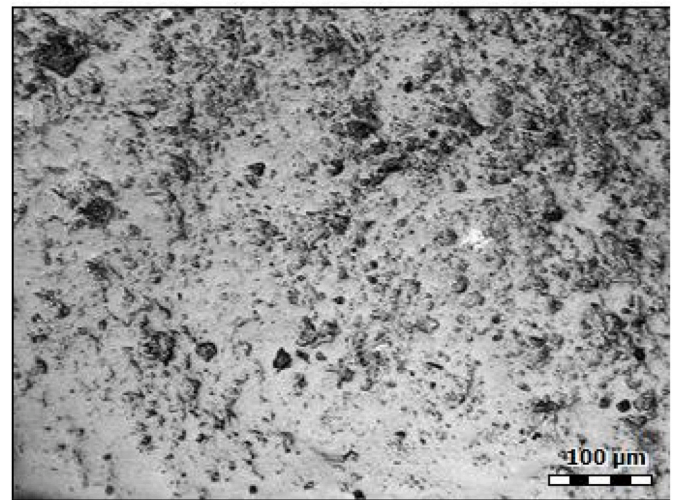


Fig. 27. DJ 3308 (Dja'de el Mughara, EPPNB), classified as semi-ripe cereal harvesting.

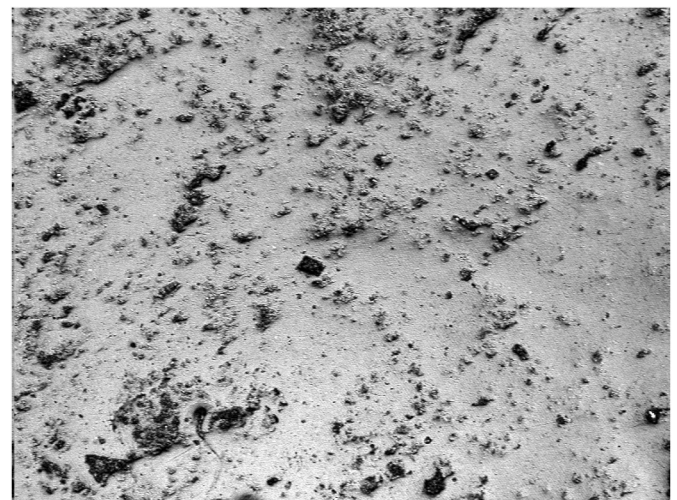


Fig. 28. DJ 1031 (Dja'de el Mughara, EPPNB), classified as semi-ripe cereal harvesting.

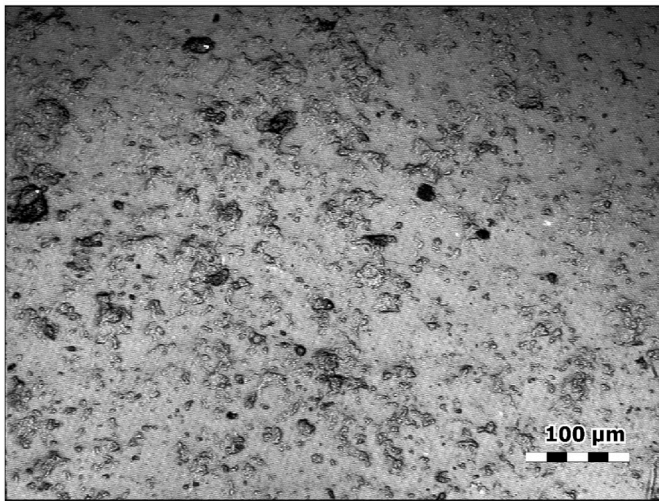


Fig. 29. Mb IVA 1976 (Tell Mureybet, EPPNB), classified as semi-ripe cereal harvesting.

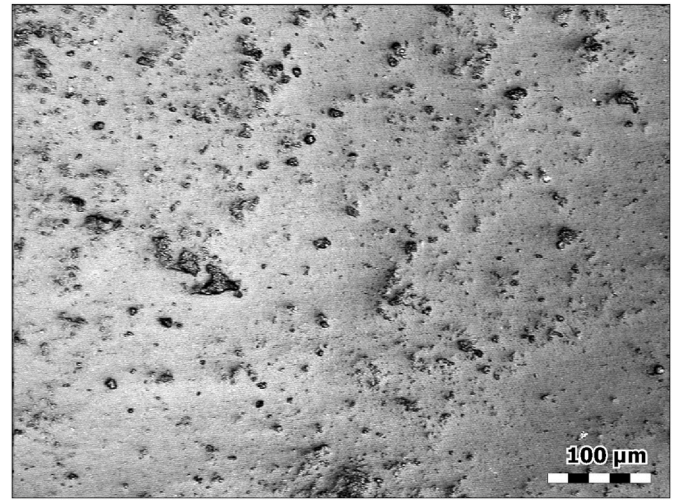


Fig. 32. JF H81 6a (Jerf el Ahmar, PPNA), classified as ripe cereal harvesting.

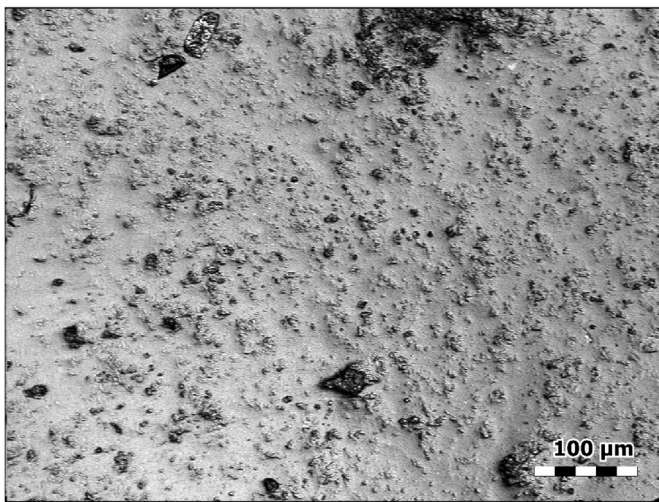


Fig. 30. JF E17 35 (Jerf el Ahmar, PPNA), classified as unripe cereal harvesting.

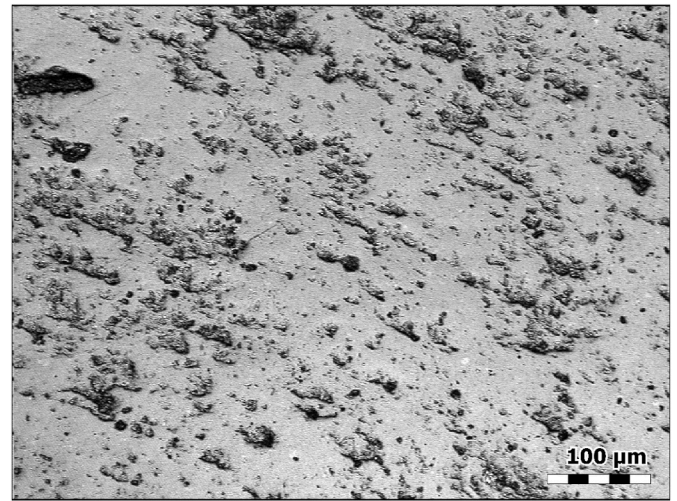


Fig. 33. JF B83 2 (Jerf el Ahmar, PPNA), classified as ripe cereal harvesting.

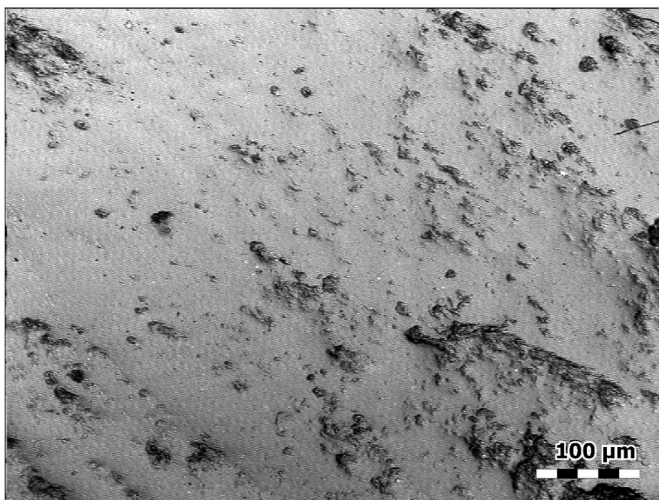


Fig. 31. Mb 73 2135 (Tell Mureybet, PPNA), classified as unripe cereal harvesting.

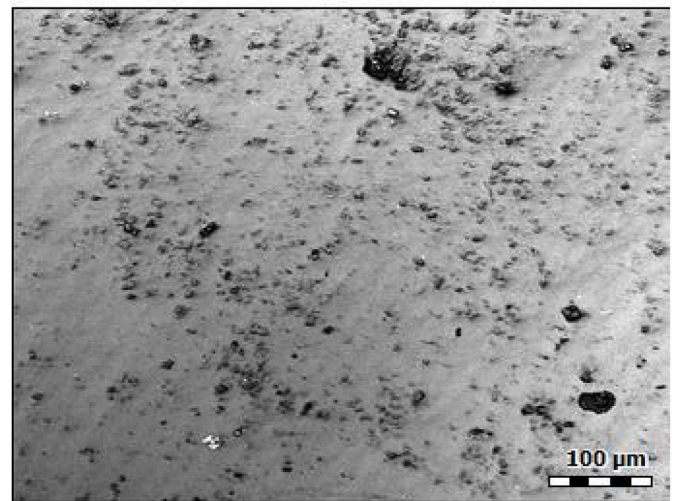


Fig. 34. Mb 74 1236 (Tell Mureybet, PPNA), classified as ripe cereal harvesting.

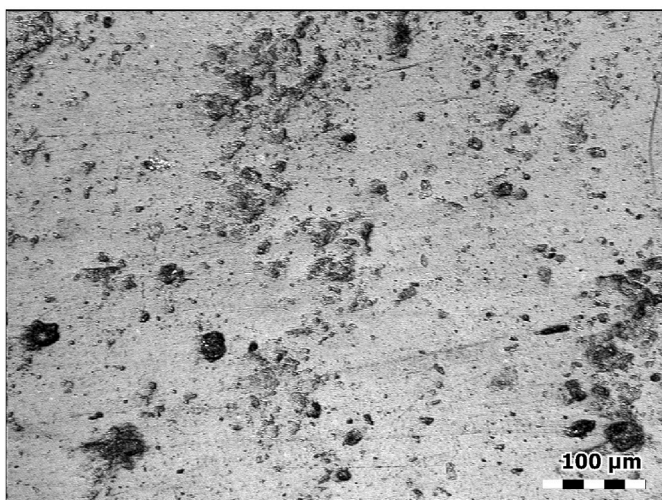


Fig. 35. DJ 1069 (Dja'de el Mughara, EPPNB), classified as ripe cereal harvesting.

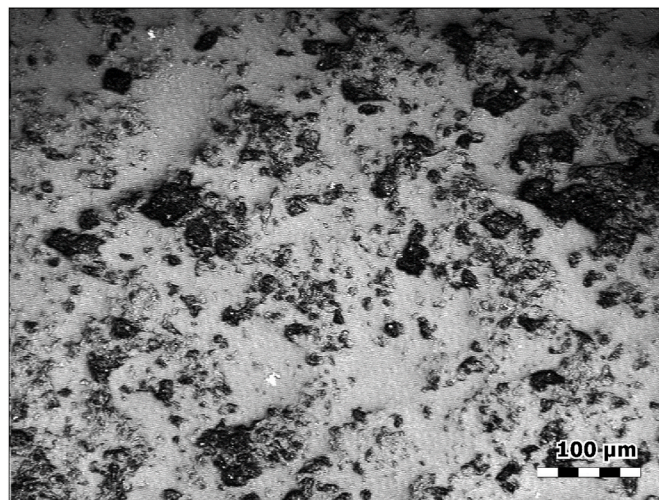


Fig. 37. AH 72D 32 F7 1 (Abu Hureyra, MPPNB), classified as semi-ripe cereal harvesting.

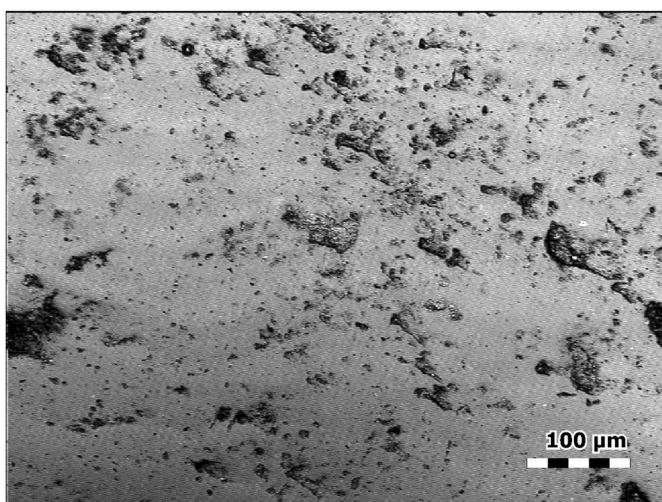


Fig. 36. Mb 74 1728 (Tell Mureybet, EPPNB), classified as ripe cereal harvesting.

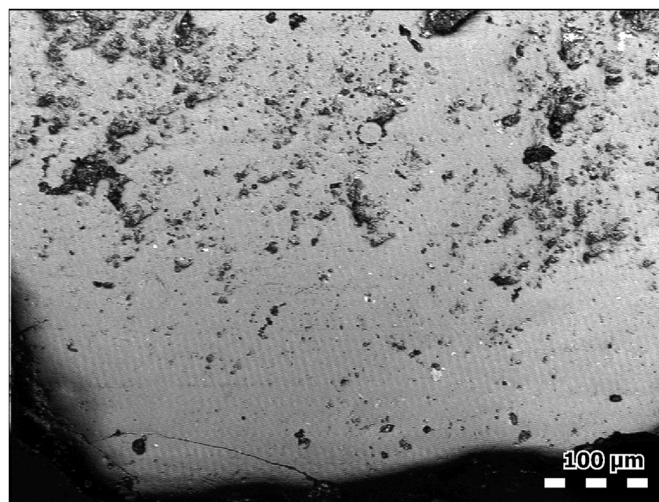


Fig. 38. HL 4D element 1 (Tell Halula, MPPNB), classified as ripe cereal harvesting.

appearance of domesticated cereals, prior to the fixation of the tough nature of the rachis, cultivated wild cereals were evolving traits that progressively allowed for a more mature harvesting of the crops. This scenario would have been possible because persistent planting and harvesting together encouraged plants to grow in synchronization (Fuller, 2007) and reduced the proportion of immature grains harvested (Fuller and Allaby, 2009).

In the Middle PPNB occupations at Abu Hureyra the harvesting of semi-ripe cereals (Fig. 37) is still more common than of fully mature ones. In this site/level domestic varieties such as free-threshing *Triticum* sp. appear, accompanied by grains of *H. spontaneum/distichum* and *T. dicocoides/dicocum* (Hillman, 2000). In the Middle and Late PPNB levels at Tell Halula (from 7600 to 7000 cal BC) sickle elements mainly fall into the group of ripe harvesting (Figs. 38 and 39), though the cutting of semi-ripe cereals is also significant (Fig. 40). Two-rowed barley (*Hordeum distichum*), naked wheat (*Triticum aestivum/durum*) and emmer (*Triticum dicocum*) were the main cereals exploited at the site. The presence of *T. aestivum/durum* demonstrates the presence of domesticated cereals, though wild cereals were also exploited (Buxó and Rovira, 2013). This is the period when sickle gloss texture shows, for the first time in the area, the dominance of ripe harvesting over unripe and

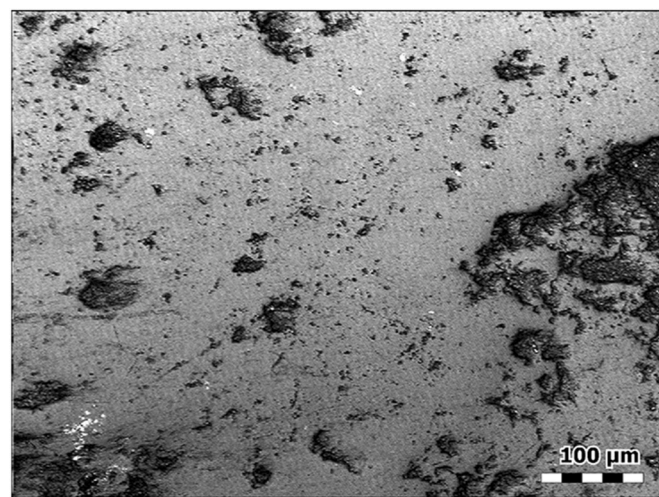


Fig. 39. HL 2C 328 (Tell Halula, LPPNB), classified as ripe cereal harvesting.

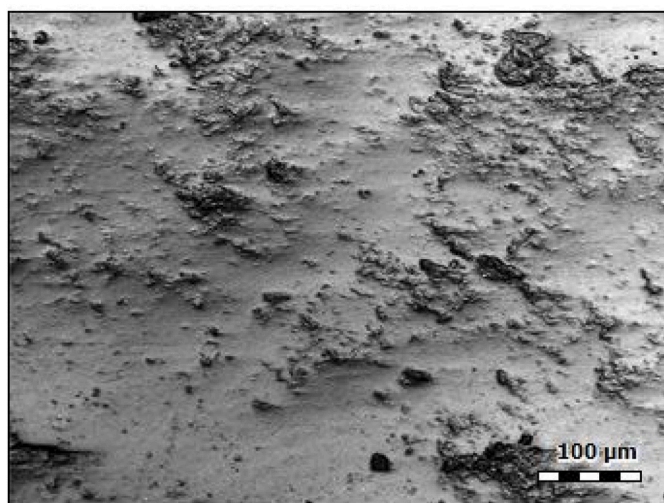


Fig. 40. HL 2C 223 (Tell Halula, LPPNB), classified as semi-ripe cereal harvesting.

semi-ripe ones.

4. Discussion

Overall, gloss texture analysis shows shifting strategies in plant harvesting during the transition to agriculture in the Levant (Weiss et al., 2006). This information, together with the archaeobotanical data, offers a more detailed view of how plants were exploited in such a crucial period. In the older sites/levels (Natufian and PPNA) a greater variety of plants were harvested, including cereals, reeds and other grasses, while from the PPNA in Middle Euphrates and the Early PPNB in Southern Levant, when large-scale cereal exploitation is detected (Willcox and Stordeur, 2012), cereal harvesting becomes dominant among plant-cutting activities. The more frequent reaping of plants other than cereals (reeds and grasses) in some sites could be influenced by environmental factors, related to the different availability of plants in each region where the sites are located. However, the chronology of the site seems to be the main factor explaining this change, as in the same sites (Tell Mureybet, Kharaysin, Abu Hureyra and Shubayqa) the variability of harvested plants is greater in the older occupation levels than in the more recent ones. The higher variety of plants that were harvested and the importance of reed cutting in the older periods (Natufian and PPNA) were already detected in previous studies using the traditional qualitative method of usewear analysis (Anderson, 1992, 1994; Unger-Hamilton, 1989). R. Unger-Hamilton (1989: 95) pointed out that *the Natufian cereal polishes exhibited somewhat more variety than the Neolithic polishes, perhaps because of the coincidental harvest of other wild plants*.

The proportion of glossed tools classified as indeterminate (Table 9) tends to decrease through time (54.8% of the tools in the Natufian period, 34.3% in the PPNA, 29.8% in the Early PPNB, 17.4% in the MPPNB and 8.3% in the Late PPNB). This would indicate that plant-cutting tools in the older periods were more often used for reaping different types of plants compared to the later periods, when tools were more often used for harvesting one type of plant, mainly cereals. Alternatively, those tools classified as indeterminate could have been used for cutting plants different from those studied in the experimentation and this will be explored in future research.

Our data also show the changes in the state of cereals when harvested from unripe, to semi-ripe and, finally, in a ripe state. The state of maturity of harvested cereals depends on multiple factors. Thus, it cannot be automatically related to the harvesting of cereals with shattering or non-shattering spikelets (see section 2.4). However, the change towards riper harvesting from 12 000 to 7000 BC strongly suggests that

the main factor explaining our results was the modification of crops in the transition to agriculture. The change in plant harvesting more closely matches the gradualist and multiregional model of explanation of cereal agriculture (Fuller et al., 2011) than the punctual “core area” one (Abbo et al., 2010). The punctual model, in which domestication was a rapid process taking place around 8500 cal BC in SE Turkey, would have implied unchanged unripe harvesting before 8500 BC in Northern and Southern Levant and sudden predominance of ripe reaping after that date, first in the North and later in the South. Nevertheless, our data indicate that the shift towards riper harvesting was already taking place before 8500 in the whole Levant and that the dominance of ripe harvesting was precocious in the South Levant compared with the North.

In this process of shift, taking gloss texture analyses and the available archaeobotanical data together, several phases can be distinguished. The dominance of unripe harvesting in Hayonim Terrace (12th millennium BC) would indicate the exploitation of wild cereals in natural stands. The presence of semi-ripe and unripe-cereal cutting in the Middle Euphrates in the 11th millennium BC suggests that, besides harvesting natural stands, human groups could have already started exploiting incipiently managed cereal fields that allowed the harvesting of plants in a semi-ripe state. At the 23 000 year-old site of Ohalo II, using the traditional qualitative usewear method, the harvesting of near-ripe semi-green wild cereals was suggested, which, according to the authors, fits well with the evidence for the earliest ever cereal cultivation at the site (Groman-Yaroslavski et al., 2016). However, no experiments on harvesting cultivated wild cereals were included in the reference collection of this study, so the identification of this activity is not supported in the comparison of the archaeological and the experimental gloss. Moreover, the development of the use-wear polish on the archaeological tools is too weak to be precise as to the type of plant harvested. Wild cereal exploitation is well documented at Ohalo II (Piperno et al., 2004; Nadel et al., 2012; Weiss et al., 2008). However, collecting methods other than sickle harvesting (uprooting, hand plucking, beating), which are well known ethnographically (Hillman and Davies, 1990; Anderson, 1992; Harlan, 1992), could have been used. Sickles allow the quick collection of cereals in the field (given close spacing of the stems and fairly similar stage of maturity) and are an indication of the intensification of cereal exploitation (Ibáñez et al., 2001; Astruc et al., 2012) that, as far as we currently know, started during the Natufian period, when glossed tools are relatively common in archaeological sites (Anderson, 1992; Unger-Hamilton, 1992; Edwards and Le Dosseur 2012; Abadi and Grosman, 2019).

The unripe, semi-ripe and ripe cereal harvesting in the PPNA and Early PPNB in the Middle Euphrates would indicate the simultaneous harvesting of cultivated wild cereals that were at different stages in the domestication process, accompanied by the marginal exploitation of cereals in natural stands. This means that roughly contemporaneous cereal fields were reaped in the same village at different stages of maturity. Probably, besides the harvesting of wild cereals in natural stands (unripe cutting), fields with wild cereals that were cultivated in different conditions were harvested. This variability could be explained by the coexistence in any one village of different cereal species or varieties that were harvested at different states of maturity. The dominance of ripe harvesting in the Southern Levant from the EPPNB and in the Middle Euphrates from the Middle PPNB onwards would correspond to the exploitation of fully domestic cereal varieties, which would have started in southern Levant around 8500 BC, a millennium before in the Middle Euphrates.

Despite the observed tendency to harvest riper cereals from 12 000 to 7000 BC in the Levant, the process is uneven in time and space. In the Middle Euphrates, for example, the proportion of semi-ripe and ripe cutting fluctuates from Mureybet II-III to Jerf el Ahmar, Dja' de III, Abu Hureyra 2 and Tell Halula. In Southern Levant, from the EPPNB, riper harvesting is observed compared to the Middle Euphrates. Geographic and chronological fluctuations in the proportions of unripe, semi-ripe and ripe cereal harvesting show that the development of plant

harvesting strategies was neither chronologically linear nor geographically homogeneous. In this process, some “involutions” implying shifts towards unripe harvesting could have taken place. This is suggested by the greater relevance of semi-ripe harvesting in the LPPNB of Tell Halula and Ba’ja with respect to earlier data in Southern and The Middle Euphrates. However, it is necessary to analyze more sickles and new archaeological contexts in both regions in order to clearly elucidate this question.

5. Conclusions

The quantitative analysis of glossed tools through confocal microscopy provides, compared with the qualitative method of usewear analysis, a more precise identification of harvesting variability in the transition to agriculture in the Levant. Our methodology permits us, combining these data with the archaeobotanical information, to elucidate the long-term change of plant harvesting in this key period. During the Natufian and the PPNA more varied types of plants were harvested than in later periods, including reeds and other types of grasses, beside cereals. From the end of the 10th millennium cal BC, coinciding with the massive cultivation of wild cereals observed by archaeobotanical studies, cereal harvesting becomes dominant. The tendency towards riper harvesting from 12 000–7000 cal BC suggests that cereals were progressively reaped in a more advanced state of maturity. This process is not strictly chronologically linear nor geographically homogeneous. Long-term change is in accordance with one of the main proposals of the protracted model for the origins of cereal agriculture (Fuller et al., 2012a,b), while the mosaic-like distribution of harvesting variability indicates that it was a process that evolved at varying rhythms in different regions of the Levant (Tanno and Willcox, 2006; Arranz-Otaegui et al., 2016). The analysis of new sites and regions will be able to reinforce these conclusions and cast more light on the complexity of the origins of cereal agriculture in South West Asia.

Data availability

The datasets generated during and/or analyzed during the current study are available in the Digital CSIC repository, <http://hdl.handle.net/10261/225522>.

Author contributions statement

Designed research: JJI-E, PCA, JEG-U; Performed research: JJI-E; Analyzed data: JJI-E, NM, FP, AJL; Interpreted data: all authors; Wrote the paper: JJI-E, AA-O, PCA, JEG-U, NM, FP, TR, Pictures of usewear: JJI.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgments

We acknowledge all the archaeologists who excavated the sites from which the glossed tools analyzed in this paper have been recovered: Dr. J. Cauvin, Dr H. Gebel, Dr. D. Stordeur, Dr- M. Molist, Dr. E. Coqueugniot, Dr. F. Valla, Dr. A.M.T. Moore and Dr. O. Bar-Yosef. The research has been funded by the Spanish Ministry of Science (PID2019-105767GB-I00), the Shelby White-Leon Levy Foundation (Publication of Tell Qarassa), the Palarq Foundation (Excavation of Kharaysin) and the Consejo Superior de Investigaciones Científicas (Proyectos Intramurales para Arqueología en el Exterior). We acknowledge support of the publication fee by the CSIC Open Access Publication Support Initiative through its Unit of Information Resources for Research (URICI). This

research is part of two MSCA-IF projects (QUANT-792544; FOUNDERS-840228),) and of the AGER project funded by the Italian Ministry of Education, University and Research (MIUR).

References

- Abadi, I., Grosman, L., 2019. Sickle blade technology in the late natufian of the southern levant. In: Asrtuc, L., McCartney, C., Brioso, F., Kassianidou, V. (Eds.), *Near Eastern Lithic Technologies on the Move: Interactions and Contexts in the Neolithic Traditions*, 8th International Conference on PPN Chipped and Ground Stone Industries of the Near East, Nicosia, November 23rd–27th 2016 Chapter: 27, Publisher: Studies in Mediterranean Archaeology Volume 150. Astrom Editions, Nicosia.
- Abbo, S., Lev-Yadun, S., Gopher, A., 2010. Agricultural origins: centers and noncenters: a Near Eastern reappraisal. *Crit. Rev. Plant Sci.* 29, 317–328.
- Abbo, S., Gopher, A., 2020. Plant domestication in the neolithic near east: the humans-plants liaison. *Quat. Sci. Rev.* 242, 106412.
- Álvarez-Fernández, A., García-González, R., Márquez, B., Carretero, J.M., Arsuaga, J.L., 2020. Butchering or wood? A LSCM analysis to distinguish use-wear on stone tools. *J. Archaeol. Sci.: Report* 31, 102377.
- Anderson, P.C., M’hamdi, M., 2014. Harvesting of the wild grass “alfa” (*Stipa tenacissima* L.) by pulling in the high Tunisian steppe: an unusual method. In: van Gijn, A., Whittaker, J., Anderson, P.C. (Eds.), *Exploring and Explaining Diversity in Agricultural Technology*. Oxbow Press, Oxford, pp. 98–102.
- Anderson, P.C., Georges, J.-M., Vargiolu, R., Zahouani, H., 2006. Insights from a tribological analysis of the tribulum. *J. Archaeol. Sci.* 33 (11), 1559–1568.
- Anderson, P.C., 1992. Experimental cultivation, harvest and threshing of wild cereals. Their relevance for interpreting the use of epipalaeolithic and neolithic artifacts. In: Anderson, P.C. (Ed.), *Prehistory of Agriculture. New Experimental and Ethnographic Approaches*. University of California, Los Angeles, pp. 118–139.
- Anderson, P.C., 1994. Insight into plant harvesting and other activities at Hatoula, as revealed by microscopic functional analysis of selected chipped stone tools in Le Gisement de Hatoula en Judée occidentale, Israël: rapport de fouilles 1980-1988. In: Lechevallier, M., Ronen, A. (Eds.), *Mémoires et travaux du Centre de recherche français de Jérusalem*, 8. Association Paléorient, Paris, pp. 277–293.
- Anderson, P.C., 2014. Uses of the wild grass *Ampelodesmos mauritanica* in northwestern Tunisia today. In: Chevalier, A., Marinova, E., Peña-Chocarro, L. (Eds.), *Chapter 6: A Versatile World: Examples of Diversity in Plant Use in Plants and People: Choices and Diversity through Time*, EARTH Series, tome 1. Oxbow Books, Oxford, pp. 287–292.
- Arranz-Otaegui, A., González Carretero, L., Richter, T., 2018a. “Founder crops” v. wild plants: assessing the plant-based diet of the last hunter-gatherers in southwest Asia. *Quat. Sci. Rev.* 186, 263–283.
- Arranz-Otaegui, A., González Carretero, L., Ramsey, M.N., Fuller, D.Q., Richter, T., 2018b. Archaeobotanical evidence reveals the origins of bread 14,400 years ago in northeastern Jordan. *Proc. Natl. Acad. Sci. U. S. A.* 31, 7925–7930. <https://doi.org/10.1073/pnas.1801071115>.
- Arranz-Otaegui, A., Colledge, S., Zapata, L., Teira-Mayolini, L.C., Ibáñez, J.J., 2016. Regional diversity on the timing for the initial appearance of cereal cultivation and domestication in southwest Asia. *Proc. Natl. Acad. Sci. U. S. A.* 113 (49), 14001–14006. <https://doi.org/10.1073/pnas.1612797113>.
- Astruc, L., Ben Tkaya, M., Torchy, L., 2011. De l’efficacité des faucilles néolithiques au Proche-Orient: approche expérimentale. *BSPF*, 2012 109 (4), 671–687.
- Bar-Yosef, O. Climatic fluctuations and early farming in west and east Asia. *Curr. Anthropol.*, Volume 52, Suppl. 4, S175.
- Beyries, S., Delamare, F.J., Quantin, C., 1988. In: Beyries, S. (Ed.), *Tracéologie et rugosimétrie tridimensionnelle in Industries lithiques, tracéologie et technologie*, 115–132 (British Archaeological Reports International Series 411).
- Borrell, F., Ibáñez, J.J., Bar-Yosef, O., 2020. Cult paraphernalia or everyday items? Assessing the status and use of the flint artefacts from Nahal Hemar (Middle PPNB, Judean Desert). *Quat. Int.* 569–570, 150–167.
- Buxó, R., Rovira, N., 2013. Tell Halula: arqueobotánica de los restos de semillas y frutos in Tell Halula: un poblado de los primeros agricultores en el valle del Éufrates, Siria. In: Molist, M. (Ed.), *Memoria Científica – Tomo I y II*. Ministerio de Educación, Cultura y Deporte. Secretaría General Técnica. Subdirección General de Documentación y Publicaciones, Madrid, pp. 359–389.
- Buxó, R., 1992. In: Anderson, P.C. (Ed.), *Quelques aspects des restes paléo-botaniques prélevés sur la Terrasse d’Hayonim (Haute Galilée) in Préhistoire de l’agriculture: nouvelles approches expérimentales et ethnographiques*, Monographie du CRA, vol. 6. CNRS, pp. 225–229.
- Calandra, et al., 2019. The effect of numerical aperture on quantitative use-wear studies and its implication on reproducibility. *Sci. Rep.* 9 (1), 6313.
- Caux, S., Galland, A., Queffelec, A., Bordes, J.C., 2018. Aspects and characterization of chert alteration in an archaeological context: a qualitative to quantitative pilot study. *J. Archaeol. Sci.: Report* 20, 210–219.
- Civán, P., Ivaničová, Z., Brown, T.A., 2013. Reticulated origin of domesticated emmer wheat supports a dynamic model for the emergence of agriculture in the fertile crescent. *PLoS ONE* 8 (11), e81955. <https://doi.org/10.1371/journal.pone.0081955>.
- Colledge, S., Conolly, J., 2010. Reassessing the evidence for the cultivation of wild crops during the younger dryas at Tell Abu Hureyra, Syria. *Environ. Archaeol.* 15 (2), 124–138.
- Colledge, S., 1998. In: Damania, A.B., Valkoun, J., Willcox, G., Qualset, C.O. (Eds.), *Identifying Predomestication Cultivation Using Multivariate Analysis in the Origins of Agriculture and Crop Domestication*, pp. 121–131 (ICARDA, Aleppo).

- Díaz-Bonilla, S., Mazzucco, N., Gassiot, E., Clop, X., Clemente Conte, I., Benavides Ribes, A., 2020. Approaching surface treatment in prehistoric pottery: exploring variability in tool traces on pottery surfaces through experimentation. *Quat. Int.* 569, 135–149.
- Douché, C., Willcox, G., 2018. New archaeobotanical data from the Early Neolithic sites of Dja' de el-Mughara and Tell Aswad (Syria): a comparison between the Northern and the Southern Levant. *Paleorient* 44/2, 45–57.
- Edwards, P.C., Le Dosseur, G., 2012. Tools and ornaments of bone. In: Edwards, P.C. (Ed.), *Wadi Hammeh 27, an Early Natufian Settlement at Pella in Jordan (Culture and History of the Ancient Near East 59)*, pp. 249–274 (Leiden).
- Evans, A.A., Donahue, R.E., 2008. Laser scanning confocal microscopy, a potential technique for the study of lithic microwear. *J. Archaeol. Sci.* 35 (8), 2223–2230.
- Evans, A.A., Macdonald, D., 2011. Using metrology in early prehistoric stone tool research: further work and a brief instrument comparison. *Scanning* 33, 294–303. <https://doi.org/10.1002/sca.20272>.
- Evans, A.A., Macdonald, D.A., Giusca, C.L., Leach, R.K., 2014. New method development in prehistoric stone tool research: evaluating use duration and data analysis protocols. *Micron* 65, 69–75. <https://doi.org/10.1016/j.micron.2014.04.006> PMID: 25041833.
- Fuller, D.Q., Allaby, R., 2009. Seed dispersal and crop domestication: shattering, germination and seasonality R.in evolution under cultivation. *Ann. Plant Rev.* 38, 238–295.
- Fuller, D.Q., 2007. Contrasting patterns in crop domestication and domestication rates: recent archaeobotanical insights from the Old World. *Ann. Bot.* 100, 903–924.
- Fuller, D.Q., Asouti, E., Purugganan, M.D., 2012a. Cultivation as slow evolutionary entanglement: comparative data on rate and sequence of domestication. *Veg. Hist. Archaeobotany* 21, 131–145. <https://doi.org/10.1007/s00334-011-0329-8>.
- Fuller, D.Q., Willcox, G., Allaby, R.G., 2011. Cultivation and domestication had multiple origins: arguments against the core area hypothesis for the origins of agriculture in the Near East. *World Archaeol.* 43, 628–652.
- Fuller, D.Q., Willcox, G., Allaby, R.G., 2012b. Early agricultural pathways: moving outside the “core area” hypothesis in Southwest Asia. *J. Exp. Bot.* 63, 617–633. <https://doi.org/10.1093/jxb/err307>.
- Galland, A., Queffelec, A., Caux, S., Bordes, J.G., 2019. Quantifying lithic surface alterations using confocal microscopy and its relevance for exploring the Châtelperronian at La Roche-à-Pierrot (Saint-Césaire, France). *J. Archaeol. Sci.* 104, 45–55.
- González-Urquijo, J., Ibáñez, J.J., 2003. The quantification of use-wear polish using image analysis. First results. *J. Archaeol. Sci.* 30, 481–489.
- Groman-Yaroslavski, I., Weiss, E., Nadel, D., 2016. Composite sickles and cereal harvesting methods at 23,000-years-old Ohalo II, Israel. *PLoS ONE* 11 (11), e0167151. [10.1371/journal.pone.0167151](https://doi.org/10.1371/journal.pone.0167151).
- Haas, M., Schreiber, M., Mascher, M., 2019. Domestication and crop evolution of wheat and barley: genes, genomics, and future directions. *J. Integr. Plant Biol.* 61 (3), 204–225. <https://doi.org/10.1111/jipb.12737>. Special Issue: Barley and wheat biology.
- Harlan, J.R., 1995. *The Living Fields: Our Agricultural Heritage*. Cambridge Univ. Press, Cambridge, UK.
- Harlan, J.R., 1992. In: Anderson, P.C. (Ed.), *Wild grass seed harvesting and implications for domestication in Préhistoire de l'agriculture: Nouvelles approches expérimentales et ethnographiques*, Monographie du CRA N° 6. Éditions du CNRS, pp. 21–28.
- Henry, O.D., 1989. *From Foraging to Agriculture: the Levant at the End of the Ice Age*. University of Pennsylvania Press, Philadelphia.
- Hillman, G., Davies, M.S., 1990. Domestication rates in wild wheats and barley under primitive cultivation. *Biol. J. Linn. Soc.* 39, 39–78.
- Hillman, G.C., 2000. In: Moore, A.M.T., Hillman, G.C., Legge, A.J. (Eds.), *Plant Food Economy at Abu Hureyra in Village on the Euphrates. From Foraging to Farming at Abu Hureyra*. Oxford University Press, New York, pp. 372–392.
- Ibáñez, J.J., Anderson, P.C., González-Urquijo, J., Gibaja, J., 2016. Cereal cultivation and domestication as shown by microtexture analysis of sickle gloss through confocal microscopy. *J. Archaeol. Sci.* 73, 62–81.
- Ibáñez, J.J., González-Urquijo, J., Gibaja, J., 2014. Discriminating wild vs domestic cereal harvesting micropolish through laser confocal microscopy. *J. Archaeol. Sci.* 48, 96–103.
- Ibáñez, J.J., González-Urquijo, J.E., Peña-Chocarro, L., Zapata, L., Beugnier, V., 2001. Harvesting without sickles. Neolithic examples from humid mountain areas. In: Beyries, S., Petrequin, P. (Eds.), *Ethno-Archaeology and its Transfers*, British Archaeological Reports International Series, vol. 983. Archaeopress, Oxford, pp. 23–36.
- Ibáñez, J.J., Lazuen, T., González-Urquijo, J., 2019. Identifying experimental tool use through confocal microscopy. *J. Archaeol. Method Theor* 26, 1176–1215.
- Ibáñez, I.J., Mazzucco, N., 2021. Quantitative use-wear analysis of stone tools: Measuring how the intensity of use affects the identification of the worked material. *PLoS ONE* 16 (9), e0257266. <https://doi.org/10.1371/journal.pone.0257266>.
- Jones, G., Charles, M.P., Jones, M.K., Colledge, S., Leigh, F.J., Lister, D.A., Smith, L.M.J., 2013. DNA evidence for multiple introductions of barley into Europe following dispersed domestications in Western Asia. *Antiquity* 87, 701–713.
- Kilian, B., Özkan, H., Walther, A., Kohl, J., Dagan, T., Salamini, F., Martin, W., 2007. Molecular diversity at 18 loci in 321 wild and 92 domesticated lines reveal no reduction of nucleotide diversity during Triticum monococcum (einkorn) domestication: implications for the origin of agriculture. *Mol. Biol. Evol.* 24, 2657–2668.
- Lerner, H., Du, X., Costopoulos, A., Ostojia-Starzewski, M., 2007. Lithic raw material physical properties and use-wear accrual. *J. Archaeol. Sci.* 34 (5), 711–722.
- Lev-Yadun, S., Gopher, A., Abbo, S., 2000. The cradle of agriculture. *Science* 288 (5471), 1602–1603. <https://doi.org/10.1126/science.288.5471.1602>.
- Macdonald, D.A., Harman, R., Evans, A.A., 2018. Replicating surface texture: preliminary testing of molding compound accuracy for surface measurements. *J. Archaeol. Sci. Rep* 18, 839–846.
- Macdonald, D.A., Xie, L., Gallo, T., 2019. Here's the dirt: first applications of confocal microscopy for quantifying microwear on experimental ground stone earth working tools. *J. Archaeol. Sci. Rep* 26, 101861.
- Maeda, O., Lucas, L., Silva, F., Tanno, K., Fuller, D.Q., 2016. Narrowing the harvest: increasing sickle investment and the rise of domesticated cereal agriculture in the Fertile Crescent. *Quat. Sci. Rev.* 145 (1), 226–237.
- Martisius, N.L., McPherron, S.P., Schulz-Kornas, E., Soressi, M., Steele, T.E., 2020. A method for the taphonomic assessment of bone tools using 3D surface texture analysis of bone microtopography. *Archaeological and Anthropological Sciences* 12, 251. <https://doi.org/10.1007/s12520-020-01195-y>.
- Martisius, N.L., Sidéra, I., Grote, M.N., Steele, T.E., McPherron, S.P., Schulz-Kornas, E., 2018. Time wears on: assessing how bone wears using 3D surface texture analysis. *PLoS One* 13. <https://doi.org/10.1371/journal.pone.0206078> e0206078.
- Nadel, D., Piperno, D.R., Holst, I., Snir, A., Weiss, E., 2012. New evidence for the processing of wild cereal grains at Ohalo II, a 23 000-year-old campsite on the shore of the sea of galilee, Israel. *Antiquity* 86: 990–1003. Novellino, D. An account of basket weaving and the use of fibre plants in the Mount aurunci regional park (Central Italy). In: Füsün, E.Z. (Ed.), *Proceedings of the Fourth International Conference of Ethnobotany (ICEB 2005)*. Yeditepe University, Zero Prod. Ltd, Istanbul, pp. 21–26, 2006.
- Novellino, D., 2006. *An Account of Basket Weaving and the Use of Fibre Plants in the Mount Aurunci Regional Park (Central Italy)*. Proceedings of the Fourth International Conference of Ethnobotany (ICEB 2005), Füsün, E.Z. Yeditepe University, Zero Prod. Ltd., Istanbul, pp. 21–26.
- Oliveira, H.R., Jacocks, L., Czajkowska, B.I., Kennedy, S.L., Brown, T.A., 2020. Multiregional origins of the domesticated tetraploid wheats. *PLoS ONE* 15 (1), e0227148. <https://doi.org/10.1371/journal.pone.0227148>.
- Pankin, A., von Korff, M., 2017. Co-evolution of methods and thoughts in cereal domestication studies: a tale of barley (*Hordeum vulgare*). *Curr. Opin. Plant Biol.* 36, 15–21. <https://doi.org/10.1016/j.cpb.2016.12.001>.
- Pankin, A., Altmüller, J., Becker, C., von Korff, M., 2018. Targeted resequencing reveals genomic signatures of barley domestication. *New Phytologist*. Special Issue: Featured papers on 'Plant proteases' 218–3, 1247–1259. <https://doi.org/10.1111/nph.15077>.
- Pedersen, P.N., Richter, T., Arranz-Otaegui, A., 2016. Preliminary analysis of the ground stone from Shubayqa 1, Jordan. *Journal of Lithic Studies* (3), 1–24. <https://doi.org/10.2218/jls.v3i3.1647> bind 3.
- Pedergnana, A., Calandra, I., Evans, A.A., Bob, K., Hildebrandt, A., Ollé, A., 2020. Polish is quantitatively different on quartzite flakes used on different worked materials. *PLoS ONE* 15 (12), e0243295. <https://doi.org/10.1371/journal.pone.0243295>.
- Pichon, F., Ibáñez-Estévez, J.J., Anderson, P.C., Douché, C., Coquegniot, É., 2021. Harvesting cereals at Dja' de el-Mughara in the northern Levant: new results through microtexture analysis of Early PPNB sickle gloss (11th millennium cal BP). *J. Archaeol. Sci.: Report* (36), 102807. Article.
- Piperno, D.R., Weiss, E., Holst, I., Nadel, D., 2004. Processing of wild cereal grains in the Upper Palaeolithic revealed by starch grain analysis. *Nature* 430, 670–673. PMID: 15295598.
- Plisson, H., 1985. *Étude fonctionnelle d'outillages lithiques préhistoriques par l'analyse des micro-usures: recherche méthodologique et archéologique*. Thèse de Doctorat. l'Université de Paris I, Paris.
- Poets, A.M., et al., 2015. Barley landraces are characterized by geographically heterogeneous genomic origins. *Genome Biol.* 16, 173. <https://doi.org/10.1186/s13059-015-0712-3>.
- Rivera, D., Obon, C., 1991. La guía INCAFO de las plantas útiles y venenosas de la Península Ibérica y Baleares. INCAFO S.A., Madrid.
- Rosen, A.M., Rapp Jr G., 1992. In: Mulholland, S.C. (Ed.), *Preliminary Identification of Silica Skeletons from Near Eastern Archaeological Sites: an Anatomical Approach in Thylacine Systematics: Emerging Issues*. Plenum, New York, pp. 129–148.
- Rosso, D.E., d'Errico, F., Queffelec, A., 2017. Patterns of change and continuity in ochre use during the late Middle stone age of the horn of africa: the porc-epic cave record. *PLoS One* 12, e0177298. <https://doi.org/10.1371/journal.pone.0177298>.
- Semenov, S., 1964. *Prehistoric Technology*. Cory, Adams and Mackay, London.
- Stemp, W.J., 2014. A review of quantification of lithic use-wear using laser profilometry: a method based on metrology and fractal analysis. *J. Archaeol. Sci.* 48, 15–25.
- Stemp, W.J., Andruskiewicz, M.D., Gleason, M.A., Rashid, Y.H., 2015a. Experiments in ancient Maya bloodletting: quantification of surface wear on obsidian blades. *Archaeological and Anthropological Sciences* 7 (4), 423–439. <https://doi.org/10.1007/s12520-014-0204-5>.
- Stemp, W.J., Chung, S., 2011. Discrimination of surface wear on obsidian tools using LSCM and ReLA: pilot study results. *Scanning* 33, 279–293.
- Stemp, W.J., Lerner, H.J., Kristant, E.H., 2018. Testing area-scale fractal complexity (Asfc) and laser scanning confocal microscopy (LSCM) to document and discriminate microwear on experimental quartzite scrapers. *Archaeometry* 60 (4), 660–677. <https://doi.org/10.1111/arcm.12335>.
- Stemp, W.J., Mikhail, M., Alastair, J.M.K., 2015b. Quantifying lithic microwear with load variation on experimental basalt flakes using LSCM and area-scale fractal complexity (Asfc). *Surf. Topogr. Metrol. Prop.* 3 (3), 034006.
- Stemp, W.J., Stemp, M., 2003. Documenting stages of polish development on experimental stone tools: surface characterization by fractal geometry using UBM laser profilometry. *J. Archaeol. Sci.* 30, 287–296.

- Stevens, N.E., Harro, D.R., Hicklin, A., 2010. Practical quantitative lithic use-wear analysis using multiple classifiers. *J. Archaeol. Sci.* 37, 2671–2678.
- Tanno, K., Willcox, G., 2012. Distinguishing wild and domestic wheat and barley spikelets from early Holocene sites in the Near East. *Veg. Hist. Archaeobotany* 21, 107–115.
- Tanno, K., Willcox, G., 2006. How fast was wild wheat domesticated? *Science* 311, 1886.
- Unger-Hamilton, R., 1992. In: Anderson, P.C. (Ed.), Experiments in harvesting wild cereals and other plants in Préhistoire de l'agriculture: nouvelles approches expérimentales et ethnographiques, Monographie du CRA, vol. 6. CNRS, pp. 211–224.
- Unger-Hamilton, R., 1989. The epi-palaeolithic southern levant and the origins of cultivation. *Curr. Anthropol.* 30 (1), 88–103.
- van Gijn, A., 1989. The Wear and Tear of Flint. Principles of Functional Analysis Applied to Dutch Neolithic Assemblages. *Analecta Praehistorica Leidensia*, Leiden.
- van Zeist, W., Bakker-Heeres, J.H., 1984. Archaeobotanical studies in the levant 3. Late palaeolithic Mureybet. *Palaeohistoria* 26, 171–199.
- Vaughan, P.C., 1985. Use-Wear Analysis of Flaked Stone Tools. University of Arizona Press, Tucson.
- Vila, A., Gallart, F., 1991. In: Vila, A. (Ed.), Aplicación del análisis digital de imágenes en Arqueología, el caso de los micropulidos de uso in Arqueología-CSIC, 131–139. CSIC, Nuevas Tendencias, Madrid.
- Watson, A.S., Gleason, M.A., 2016. A comparative assessment of texture analysis techniques applied to bone tool use-wear. *Surf. Topogr. Metrol. Prop.* 4 (2), 024002.
- Weide, A., Hodgson, J.G., Leschner, H., Dovrat, G., Whitlam, J., Manela, N., Melamed, Y., Osem, Y., Bogaard, A., 2021. The association of arable weeds with modern wild cereal habitats: implications for reconstructing the origins of plant cultivation in the levant. *Environ. Archaeol.* <https://doi.org/10.1080/14614103.2021.1882715>.
- Weiss, E., Kislev, M.E., Hartmann, A., 2006. Autonomous cultivation before domestication. *Science* 312, 1608–1610.
- Weiss, E., Kislev, M.E., Simchoni, O., Nadel, D., Tschauer, H., 2008. Plant-food preparation area on an Upper Paleolithic brush hut floor at Ohalo II, Israel. *J. Archaeol. Sci.* 35, 2400–2414.
- Werner, J.J., 2018. An experimental investigation of the effects of post-depositional damage on current quantitative use-wear methods. *J. Archaeol. Sci.: Report* 17, 597–604.
- Willcox, G., 1992. Archaeobotanical significance of growing Near Eastern progenitors of domestic plants at Jalès (France). In: Anderson, P.C. (Ed.), Préhistoire de l'agriculture: Nouvelles approches expérimentales et ethnographiques, pp. 159–178. Monographie du CRA N° 6, Editions du CNRS.
- Willcox, G., 2012. In: Potts, D. (Ed.), The Beginnings of Cereal Cultivation and Domestication in Southwest Asia in A Companion to the Archaeology of the Ancient Near East, pp. 163–180 (Blackwell).
- Willcox, G., Formite, S., Herveux, L., 2008. Early Holocene cultivation before domestication in northern Syria. *Veg. Hist. Archaeobotany* 17, 313–325.
- Willcox, G., Stordeur, D., 2012. Large-scale cereal processing before domestication during the tenth millennium BC cal. in northern Syria. *Antiquity* 86 (331), 99–114.
- Zohary, D., Hopf, M., 2000. Domestication of Plants in the Old World, third ed. Clarendon Press, Oxford.