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Discriminating wild vs domestic cereal harvesting micropolish through laser confocal microscopy

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ABSTRACT

Though it is well established that cereal domestication took place in the Near East, between 10,000 and 7000 cal BC., there are still many open questions about when, where and how this process took place. As one way to advance these questions, we propose focusing on the use-wear analysis of sickle elements. Wild cereals must be harvested before the complete maturation of the plant, while domestic cereals are harvested ripe. This difference in the degree in humidity when harvesting provokes differences in the characteristics of the use-wear polish. In this paper we measure both types of use-wear polish in experimental tools through laser confocal microscopy. Later, the discriminant function which distinguishes both types of use-wear polishes is used to classify four archaeological sickle elements from Late PPNB, Middle PPNB, PPNA and Natufian archaeological levels. Preliminary results show that the classification of the archaeological sickle elements according to the wild/semi-green vs domestic/ripe experimental tools is coherent with archaeobotanical data.

1. Introduction

The invention of agriculture is one of the most important cultural achievements of humankind. In the Near East, the last hunter–gatherers began to make their first agricultural experiments in the tenth millennium cal BC, domesticating several species of cereals and legumes. Later, agriculture spread from there to Europe, North Africa and central and southern Asia. Among the founder crops, cereals were and still continue to be the most relevant in human diet.

The use of wild cereals for human consumption has been documented in the Near East, at the site of Ohalo II (Kislev et al., 1992), dated about 19,000 cal BC. Around 12,000 cal BC the consumption of wild cereals intensified among the last hunter–gatherer groups, and the first signs of farming have been documented about 9700 cal BC, although the seeds grown were still morphologically wild. The first domesticated cereals appear about 8300 cal BC (Colledge and Conolly, 2007), and these become more widespread at Near East sites after 8000 cal BC.

Growing wild cereals led to their domestication through the selection of traits in what is known as the domestication syndrome (Brown et al., 2009). These traits are: 1. loss of the dispersal ability of the seeds; 2. loss of the grain dispersal aids; 3. increase in grain size; 4. loss of sensitivity to environmental cues for germination and flowering; 5. synchronous ripening; 6. uniform growing habit of the plants; and 7. enhanced bread-making capability.

The dominant paradigm to explain the origin of cereal-growing proposes that the process of genetic selection took place at some very specific geographical sites in the Near East, where the wild cereals acquired, in a single and short selection process (monophyletic), the traits of domestic cereals (Diamond, 1997; Lev-Yadun et al., 2000; Salamini et al., 2002). Later, these cereals and agricultural methods expanded to other parts of the Near East. This paradigm was established in the 1990s, mainly from the genetic study of modern cereals, both wild and domestic strains. However, recent archaeobotanical data show that domestication was a protracted process, which lasted for over a millennium (Tanno and Willcox, 2006), and was preceded by a stage of wild-cereal growing (Weiss et al., 2006). Archaeobotanical data suggest that the invention of agriculture was a multi-regional process within the context of the Near East (Willcox, 2005).

At the present time, a lively debate is being maintained between the supporters of the mono-focus model, which is mainly based on

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the genetic data, and the advocates of multi-focus models, who highlight the importance of the archaeo-botanical information (Fuller et al., 2011).

Another main topic of research, which is connected with the question of the mono or multifocus origin, is when the first experiences of cultivation took place. This is a complex topic, as it is very difficult to find direct evidence of the cultivation of wild cereals. Indirect evidence, such as the increase in the proportion of weeds, the quantity of sickle blades and their intensity of use, or the variety of cereal species, has been used to propose that the first experiences of cultivation took place during the PPNA, in the first half of the 10th millennium cal BC (Willcox et al., 2008). However, some archaeobotanical evidence at Abu Hureyra would indicate that domestic cereals already existed in the 11th millennium cal BC in the Euphrates region (Hillman et al., 2001).

Therefore, despite the considerable progress made in recent decades, an understanding of the Near Eastern origin of agriculture is still one of the greatest challenges in archaeological research (Zeder et al., 2006). When, where and how cereal domestication took place are still open questions. In order to advance in these crucial questions we propose applying use-wear analysis to sickle elements, as these tools are largely present in archaeological sites and, as we argue in this paper, the characteristics of the use-wear polish can provide relevant data on the process of cereal domestication.

We are aware that harvesting with sickles played a major role in cereal domestication. Harvesting would have provoked the progressive unconscious selection of mutant individuals among the population of wild cereals which led to domestication (Hillman and Davies, 1990). Wild cereals must be harvested before the complete maturation of the plant to avoid the loss of grain, because of the fragile characteristics of the basal rachis of the seeds (Anderson, 1992: 191; Hillman and Davies, 1990; Willcox, 1992: 167). On the contrary, domestic cereals are harvested ripe (Hillman, 1984, 1985; Peña-Chocarro et al., 2009), except in punctual cases (i.e. for the elaboration of freekeh).

Variables such as type of cultigens, soil type, worker strength, harvesting technique and cutting height influenced different traits of cereal use-wear development, mainly in the density of striations, position of traces and invasiveness (Anderson, 1991; González Urquijo et al., 2000; Unger-Hamilton, 1989, 1991; Yamada, 2000). The association of domestic cereals in cultivated fields with an increased number of striae has been explained by the dusty stems found in disturbed fields (Korobkova, 1981; Unger-Hamilton, 1985, 1992: 217). However, it is difficult to justify how ground disturbance during seed sowing could influence the quantity of abrasive particles in the cereal stems during the harvesting period. Other variables more probably related to this factor are cutting height and work intensity, with lower cutting and more intensive work resulting in greater presence of striations (Anderson, 1992; González Urquijo et al., 2000). Most importantly, the characteristics of the use-wear polish are clearly related to the difference in the degree of humidity when harvesting. Use-wear polish from harvesting domestic cereals is flatter and more abraded than the polish produced by cutting wild cereals (Figs. 1 and 2) (Anderson, 1991; Unger-Hamilton, 1991). Thus, a precise discrimination of the wild vs domestic harvesting use-wear traces and of the intermediate steps would result in a better understanding of the domestication process, as it would allow us to locate in time and space the different steps of the domestication process across the Near East.

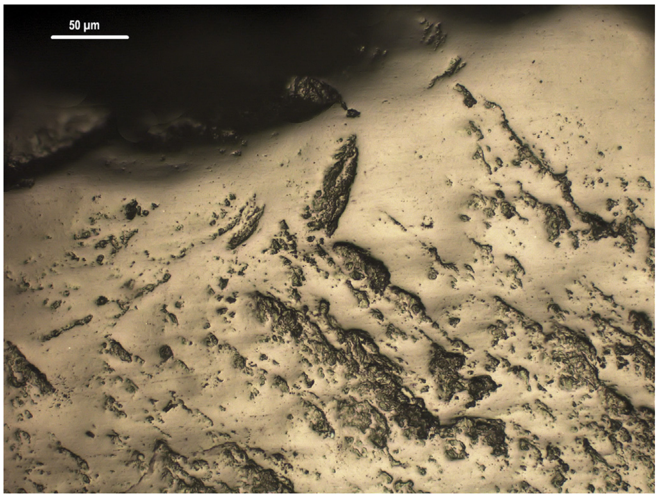

Fig. 1. Use-wear micropolish from harvesting wild cereals (*Triticum dicoccoides* and *Hordeum spontaneum*), for 4 h, 200×.

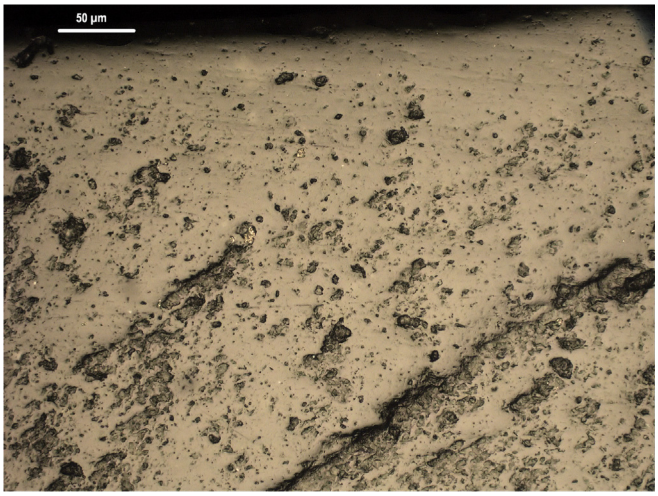

Fig. 2. Use-wear micropolish from harvesting domestic cereal (*Triticum spelta*), for 7 h, 200×.

2. Material and methods

Visual characterization permits a first approach to the characteristics of harvesting polish, but it is a limited method for discriminating wild vs domestic harvesting use-wear polish and the intermediate steps. This precise discrimination should be determined and demonstrated through quantitative methods. Different methods have previously been used to attempt a quantification of use-wear polish, such as interferometry (Dumont, 1982), image analysis (Bietti et al., 1994, 1998; González-Urquijo and Ibáñez, 2003; Grace et al., 1987; Knutsson, 1988; Pijoan et al., 2002; Vila and Gallart, 1993), measure of surface brightness levels (Vardi et al., 2010) or texture analysis through atomic force microscopy (Kimball et al., 1995). During the last decade laser confocal microscopy has proved to be an accurate and easy to use technique for use-wear quantification (Evans and Donahue, 2008; Evans and Macdonald, 2011; Stemp and Chung, 2011; Stemp et al., 2013 Stevens et al., 2010). The general characteristics of laser confocal microscopy have already been explained in previous studies. For this analysis, we have used a Sensofar Plu Neox laser scanning confocal microscope in the CD6 Laboratory at the Universitat Politecnica de Catalunya (Terrassa, Spain).

This is a first step in an ongoing research program. For the moment, 11 sickle elements have been measured (Table 1). Seven of them were experimental tools, which were used for harvesting

Table 1
Experimental program, measured areas and measured subsamples in each experimental sickle element. The outliers have been excluded from the number of measured subsamples.

Number of experiment	Harvested cereal	Time of use (minutes)	Origin of the flint	Quantity of measured areas	Quantity of measured subsamples
1	*T. spelta* (domestic)	270	Treviño (Spain)	4	23
2	*T. spelta (domestic)*	270	Treviño (Spain)	10	60
3	*T. spelta* (domestic)	420	Palmyra (Syria)	8	67
4	*T. spelta* (domestic)	420	Palmyra (Syria)	8	65
5	*T. spelta (domestic)*	420	Palmyra (Syria)	8	70
6	*T. dicoccoides H. spontaneum* (wild)	240	Charente (France)	9	64
7	*T. dicoccoides H. spontaneum* (wild)	240	Charente (France)	6	45

wild ($n = 2$) and domestic cereals ($n = 5$). The other four elements were recovered in archaeological sites (see below). Experiments of wild cereal harvesting were carried out at the Jebel el Arab (Syria), in 2009 and 2010 (Fig. 4). Stands of *Triticum dicoccoides* and *Hordeum spontaneum* were reaped at the beginning of May, when the grain was already formed but the plants were still not completely mature. We used a slightly curved sickle made of wood for a total of four hours, which would total around 2880 sickle strokes. Four fine-grained lithic elements were inserted in the sickle, made of flint coming from outcrops in La Charente basin (France). Experiments in harvesting domestic cereals were carried out in Zureda (Asturias) in September 1993. Cultivated fields of *Triticum spelta* were reaped with two wooden sickles which replicated the Karenovo-type sickles. One of them, with lithic insertions made of flint from the Palmyra basin (Syria), was used for seven hours (around 5400 strokes), while the other, with lithic insertions made of flint from Treviño (Alava, Spain) was used for 4 h and 30 min (around 3240 strokes). In all the experiments the stems were cut off at a height of around 20 cm above the ground surface.

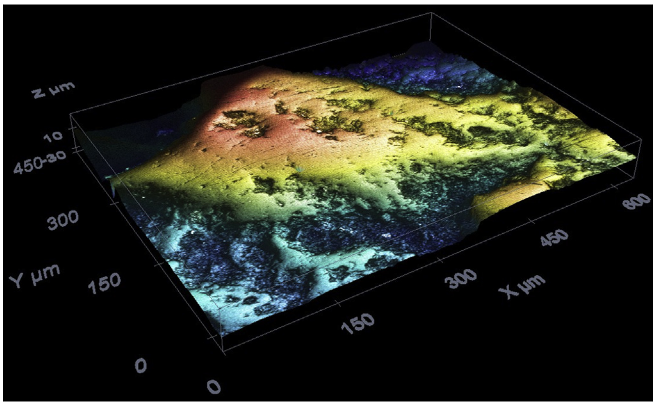

Fig. 3. 3D image through laser confocal microscopy of use-wear micropolish from harvesting domestic cereals.

Fig. 4. Harvesting wild cereals in the Jebel el Arab (Syria).

Two sickle elements recovered from the experimental tool used for harvesting wild cereals, three from the experiment of domestic harvesting for seven hours and two from the experiment of domestic harvesting for four hours and 30 min were used for the analysis (Table 1). We measured the texture of micropolish in these experimental tools to obtain a discriminant function which could allow us to distinguish use-wear polishes from both types of tasks. We also measured unpolished surfaces of the three types of flint (Table 2), in order to know how the texture of the natural flint surface varies and to assess the hypothetical role of this variability in use-wear polish quantification.

The archaeological sickle elements (Table 3) were found in the sites of Tell Mureybet (Ibáñez, 2008) (one sickle element from the Natufian levels and another one from the PPNA levels) and Tell Halula (Molist, 2001) (one from the Mid PPNB levels and the other one from the Late PPNB levels). Both sites are located in the Middle Euphrates (Syria). Tell Mureybet is a mound with Natufian, PPNA and PPNB levels. Natufian levels, dated in the second half of the 11th millennium cal BC, include hearths in open areas, while in the PPNA levels, dated in the 10th millennium cal BC, some rounded and square houses are placed around a rounded sunken building which probably had collective functions. Tell Halula is an archaeological mound with Mid PPNB, Late PPNB and Pottery Neolithic levels. Both Mid PPNB levels, dated in the mid-9th millennium cal BC, and the Late PPNB levels, dated in the late 9th millennium cal BC, possess rectangular and multicellular houses. The archaeological periods that the archaeological sickle elements are attributed to represent four main successive phases in the process of cereal domestication.

The experimental tools were submerged in a 30% hydrogen peroxide solution for 3 h, in order to eliminate the organic residues. The archaeological and the experimental tools were cleaned with soapy water. Later, they were observed under a metallographic microscope Leica DM 2500 M at 100 and 200 magnifications, in order to detect the appropriate areas to be measured. Between four and seven areas with harvesting polish of 650 × 500 μm were measured on the eleven tools with the Sensofar Plu Neox laser scanning confocal microscope, using a 20× (0.45 NA) objective, with a spatial sampling of 0.83 μm, an optical resolution of 0.31 μm, a vertical resolution of 20 nm and the z-step interval at 1 μm (Fig. 3). The zones where the use-wear polish was most developed, along the edge of the sickle elements, on both their ventral and dorsal sides were chosen for the analysis. A total of 92 areas of 650 × 500 μm were taken from the experimental and the archaeological tools. Fifty three areas corresponded to the 11 experimental tools (Table 1), 17 to the unpolished areas of the three types of flint used in the experimental program (Table 2) and 22 to the 4 archaeological tools (Table 3). Nine sub-areas of 100 × 100 μm were sampled from each 650 × 500 μ area The nine sub-areas were chosen regularly by distributing nine 100 × 100 μm sampling windows across each 600 × 500 μm surface, in three columns and three rows.

Table 2
Number of unpolished measured areas and subsamples for each type of flint used in the experimental program.

Origin of flint	Number of measured areas	Number of measured subsamples
Treviño (Spain)	5	45
Palmyra (Syria)	6	54
Charente (France)	6	54

Table 3
The four archaeological sickle elements, the measured areas and the measured subsamples of each archaeological tool. The outliers have been excluded from the number of measured subsamples.

Archaeological site	Period	Number of measured areas	Number of measured subsamples
Tell Halula	Late PPNB	6	46
Tell Halula	Mid PPNB	5	35
Tell Mureybet	PPNA	6	45
Tell Mureybet	Natufian	5	30

These sub-areas were processed and later measured with the Sensomap software, from Digital Surf. The processing of the subsamples before measuring tried, first, to correct the lack of horizontality of the sampled surface under the microscope. For this, a leveling operator using the Least Squares (LS) Plane Method was utilized. Processing was also used to separate polish texture from the irregularities of the flint surface in the sampled area. The relief of an object, measured using a surface finish measurement instrument, can be separated in different components, depending on the motifs' wavelengths. The notion of wavelength comes from optics and signal processing. The smaller the wavelength, the more altitude variations the surface contains in the same horizontal length. To isolate the polish texture, we used Roughness and Waviness Filtering, separating data frequencies (or wavelengths) into two parts, one having long wavelengths or low frequencies (waviness), the other having short wavelengths or high frequencies (roughness), with the latter being the information kept for the quantitative analysis. We have chosen to measure the texture elements of short wavelengths because we consider that they keep most of the information of the micropolish characteristics allowing the distinction of the contact material, while the texture elements of longer wavelengths would be more related to the degree of polish development and to the variability of flint microtopography. As the separation criterion, a Robust Gaussian filter type was used, with 8 μm as the threshold cut-off.

Different parameters of texture measurement offered by the Mountain 6 software, which are currently used for industrial purposes, were tested for the subsamples, choosing those which offered significant discriminant capacity (through Wilks' lambda distribution test) between the use-wear polish from wild and domestic harvesting tools. Ten parameters of surface roughness were chosen for the analysis: Sa, the arithmetical mean height; Sq, the standard deviation of the height distribution; Sp the height between the highest peak and the mean plane; Sv, the depth between the mean plane and the deepest valley; Sz, the height between the highest peak and the deepest valley; Sal, the ratio of the area of the material at a specified height (cut level at 1 μm under the highest peak) to the evaluation area; Sdc, the extreme peak height or the difference in height between q% and p% material ratio ($q = 10$%, $p = 80$%). The remaining three parameters were obtained through a previous vectorization of the micro-valleys network of the surface. This means that all the furrows contained by a surface are calculated. This parameter works well for discriminating both types of harvesting polish. After vectorization, by selecting all the furrows (100%), the maximum depth, mean depth and mean density of furrows were measured. All these ten parameters were used as predictors in all the discriminant analysis carried out for this study.

Discriminant function analysis builds a predictive model for group membership, which is composed of a discriminant function based on linear combinations of predictor variables, which provide the best discrimination between groups. Discriminant statistics were used, from the SPSS statistic package, in order to obtain the discriminant function for both types of harvesting polish and to calculate the distance between the experimental tools and the archaeological ones. This type of statistics is very sensitive to the presence of outliers, which can distort the final result of the classification. Because of this, the outliers for the ten parameters used in the analyses were eliminated (that means 9% of measured areas from experimental tools and 11% from archaeological tools). This was done by resorting to the box diagram of each variable, eliminating the cases for which their distance from the mean was more than three times the standard deviation.

First, the discriminant function distinguishing between domestic and wild cereal harvesting polish was obtained. A cross validation or 'jack-knife' classification was used to check the discriminant power of the function more adequately. For this, each case was classified by the functions derived from all cases other than that case, resulting in a blind classification of each case. Later, the seven experimental tools were submitted to the discriminant function. Finally, this statistical technique was also used to classify the unpolished natural surfaces and to compare the four archaeological sickle elements with the wild and domestic cereal harvesting tools.

3. Results

The discriminant function analysis allows consistent discrimination between the subsamples of use-wear polish resulting from harvesting wild/semi-green cereals and those resulting from harvesting domestic/ripe ones. Significant mean differences were observed for all the predictors mentioned in the previous section. While the log determinants were quite similar, Box's M indicated that the assumption of equality of covariance matrices was violated. However, given the large sample, this problem is not regarded as serious. The test correctly classified 93.2% of the subsamples (Table 4). The discriminant capacity of the function is more accurate for the domestic cereal harvesting polish (98.7% correct) than for the wild cereal harvesting one (78.4% correct), because the subsamples of this type of polish display greater variability. The cross validated classification showed that overall 92.4% were correctly classified, while the rate descends to 76.6% for the subsamples of wild cereal harvesting. The Mean depth of furrows, Maximum depth of furrows and Sz, are the most important predictors, while mean density of furrows and Sal show less influence in the discriminant function.

Discriminant function analysis of the seven experimental sickle elements (Fig. 5) significantly distinguishes the five domestic

Table 4
Classification through canonical discriminant analysis of subsamples of wild and domestic cereal harvesting micropolish. In total, 93.2% of the subsamples are correctly classified. In cross validation, each case is classified by the functions derived from all cases other than that case.

	Type of harvesting polish	Predicted group membership	
		Domestic	Wild
Original	Domestic	295 (98.7%)	4 (1.3%)
	Wild	24 (21.6%)	87 (78.4%)
Cross-validated	Domestic	294 (98.3%)	5 (1.7%)
	Wild	26 (23.4%)	85 (76.6%)

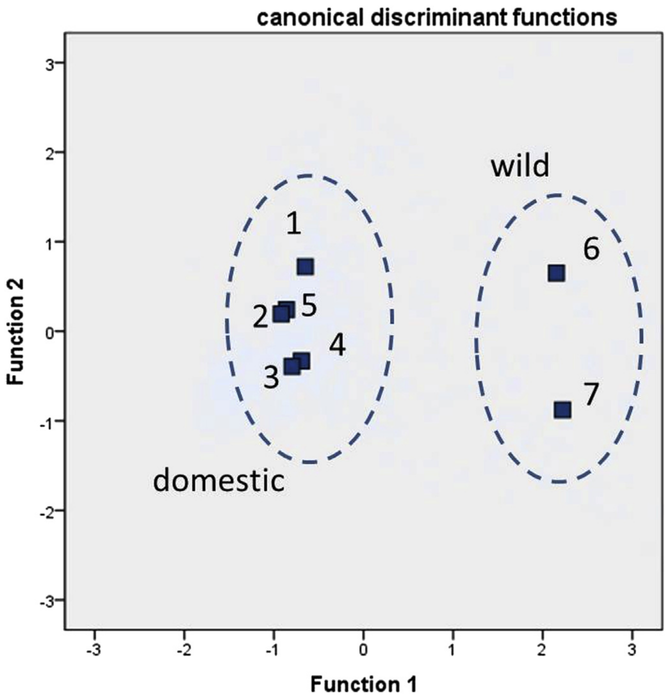

Fig. 5. Graph with the results (distance between centroids) of the canonical discriminant analysis of the seven experimental tools, five of them used in domestic cereal harvesting (numbers 1–5) and two in wild cereal harvesting (numbers 6 and 7). The two discriminant functions represented on the axes of the graph amount to 86.3% of the variance.

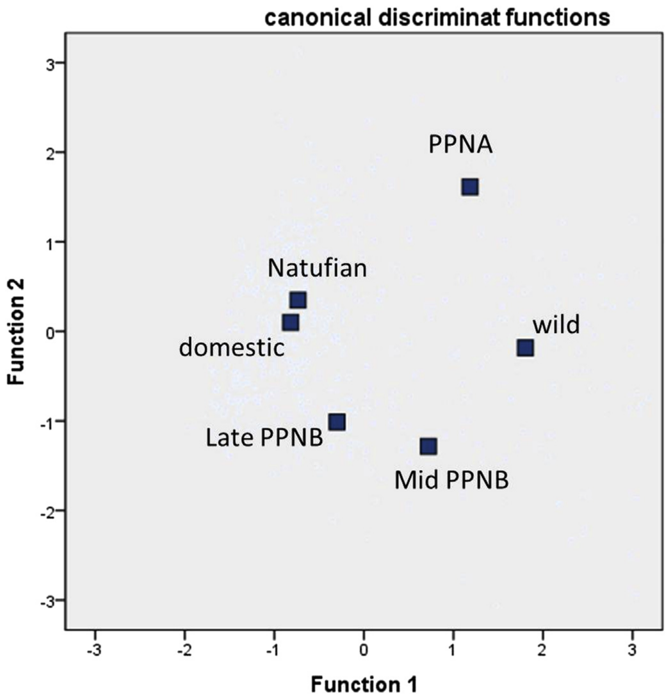

Fig. 6. Graph with the results (distance between centroids) of the canonical discriminant analysis of the four archaeological tools, compared with the measured subsamples of domestic and wild cereal harvesting experiments.

harvesting tools from the two wild harvesting ones also when they are compared individually. The first two discriminant functions represented in the axes of the graphic amount to 86.3% of the variance. The first three discriminant functions out of the 6 grouping the seven sickle elements are significant (Wilk's lambda). Domestic harvesting tools are better grouped than wild harvesting ones, as we observed previously, when the whole group of domestic harvesting subsamples was compared with the whole group of wild harvesting ones. The domestic harvesting tools show similar results irrespectively of the type of flint used in them, whether the Palmyra flint (experiments 1, 2 and 3) or the Treviño type (experiments 4 and 5).

When comparing the unpolished surfaces of the three types of flint two by two, the discriminant function analysis shows that the Palmyra flint is significantly different (Wilk's lambda) from the other two, while the Charente and Treviño ones do not present significant discriminant results between them. The discriminant analysis with the three types of flint shows that the flint from Palmyra and from Charente show quite defined textural characteristics (around 70% of correct intragroup cross-validated classification), while it is the Treviño flint which is more variable and shows a high level of overlapping, especially with the one from Charente.

Finally, we proceeded to compare the results of the subsamples of wild and domestic cereal harvesting polishes with the four archaeological tools (Fig. 6). On doing this, we observed that the PPNA and the Mid PPNB sickle elements are placed between the wild and the domestic cereal harvesting tools. The Late PPNB sickle is located nearer to the domestic harvesting tools, while the Natufian sickle polish is very similar to the domestic harvesting tool polish. This classification is confirmed by the discriminant analysis between both types of experimental harvesting polish and each archaeological sickle elements. Blind classification of the archaeological subsamples, in which each archaeological subsample was classified as either domestic or as wild harvesting polish (Table 5), indicates that the Late PPNB and the Natufian sickle element subsamples are mostly classified as domestic while the Mid PPNB and the PPNA sickle elements show a more equilibrated distribution, with a few more subsamples classified as wild than as domestic harvesting polish (Table 6).

4. Discussion

The discrimination of the sickle elements used for harvesting wild cereals from those used for cutting domestic cereals is statistically significant. These results suggest that the quantitative distinction of both types of traces can be achieved consistently. This

Table 5
Classification through canonical discriminant analysis of subsamples of the unpolished surfaces of Palmyra, Charente and Treviño flint. In cross validation, each case is classified by the functions derived from all cases other than that case.

	Type of flint	Predicted group membership		
		Palmyra	Charente	Treviño
Original	Palmyra	42 (79.2%)	8 (15.1%)	3 (5.7%)
	Charente	10 (13.9%)	57 (79.2%)	5 (6.9%)
	Treviño	4 (9.1%)	18 (40.9%)	22 (50.0%)
Cross-validated	Palmyra	38 (71.7%)	9 (17.0%)	6 (11.3%)
	Charente	12 (16.7%)	49 (68.1%)	11 (15.3%)
	Treviño	8 (18.2%)	21 (47.7%)	15 (34.1%)

Table 6
Blind classification through discriminant analysis of subsamples of four sickle elements as domestic or wild cereal harvesting polish.

Period	Domestic	Wild
Late PPNB	38 (80.9%)	9 (19.1%)
Mid PPNB	15 (41.7%)	21 (58.3%)
PPNA	19 (41.3%)	27 (58.7%)
Natufian	29 (96.7%)	1 (3.3%)

fact shows the potential of confocal microscopy for distinguishing different types of use-wear polish, as has been stated in several previous studies (Evans and Donahue, 2008; Evans and Macdonald, 2011; Stemp and Chung, 2011; Stemp et al., 2013; Stevens et al., 2010). This study indicates that even use-wear polishes which look similar, as those generated by domestic ripe (dry) and wild semi-green (wetter) cereal harvesting can be consistently discriminated.

However, it is necessary to take account of other variables which could affect the reliability of this inference, such as the degree of development of the polish or the type of flint in which the tools were made, to cite the more relevant ones. Let us examine how these variables could affect the reliability of our measurements.

Use-wear polish is a dynamic phenomenon, as the alteration of the flint surface is progressive, so micropolish changes in appearance during the time of use of the tool (Grace, 1989: 70). Polish begins to appear at the very edge of the tool, then will develop in the elevated parts of the microtopography and, finally, it spreads into the lower areas as work proceeds (Juel Jensen, 1994:13). P. Vaughan (1985: 28) distinguishes three progressive phases of micropolish development, the *generic weak polish*, the *smooth pitted polish* and the *well developed* or *diagnostic polish*. All the other variables being equal, activities carried out for a longer time result in better developed micropolishes. In our experimental program, among the five sickle elements used for harvesting domestic cereals, two were used for 270 min and the other three for 450 min. Despite this, they group together correctly. Moreover, the wild cereal harvesting sickle was used for 240 min, a similar time to one of the domestic cereal harvesting experiments and, despite this, they discriminate adequately. This suggests that, in our analysis, the time of use is not a relevant variable affecting micropolish texture quantification. This is because we have sampled from all the sickle elements those areas with a high degree of micropolish development. In fact, different steps of micropolish development are present on the same used edge, depending on the higher or lower intensity of the contact between specific areas of the edge and the worked material. Thus, areas of micropolish with a similar degree of development can be chosen and measured even if we are comparing tools with a different time of use. Because of this, choosing areas with similar micropolish development has allowed us to isolate this important variable in our study.

This way of treating the variable of micropolish development is valid for this first step of research, where we are interested basically in testing the capacity of laser confocal microscopy for discriminating types of use-wear micropolish which look very similar to the analysts. However, for a more advanced stage in use-wear micropolish quantification, this variable should be treated in a quantitative way (González-Urquijo and Ibáñez, 2003). In this way, every measurement of texture should be associated with its specific degree of development of the micropolish, so a regression function should relate the two continuous variables (degree of development of the micropolish and worked material). However, in this preliminary state of our research, we have tried to isolate the variable of the degree of development of the micropolish by choosing for the analysis those areas in the experimental tools which show a similar degree of development of the micropolish.

The nature of the flint surface can influence the characteristics of the use-wear micropolish (Lerner et al., 2007), as coarse-grained flints exhibit more discontinuous distributions of micropolish than fine-grained ones. The experimental tools used for harvesting both types of cereals were made of different types of flint, the two sickle elements used for cutting wild cereals coming from La Charente (France) and the five used for harvesting domestic cereals coming from Palmyra (Syria) and Treviño (Spain). The three types of flint used for the experimental tools are fine-grained, so we think that the influence of this variable in the micropolish characteristics is minimal. However, to get a more precise knowledge on the influence of the flint variability in our study, we have measured some unpolished surfaces. We have observed that the Palmyra and Charente flint discriminate quite well between them, while the Treviño variety shows more variability in texture, overlapping with the Charente one. Despite the fact that the two sickle elements used in domestic cereal cutting were made from two varieties of flint with different textures (two elements in Treviño flint and the other three in the Palmyra variety), their polished surfaces show similar characteristics. Moreover, even though two of the sickle elements used in domestic cereal harvesting and the two sickle elements used for wild cereal cutting, were made in varieties of flint which bear similar textural characteristics (Treviño and La Charente) the two types of harvesting micropolish on these tools discriminate adequately. This indicates that, in this study, flint variability is not a relevant variable affecting the capacity of discriminating both types of harvesting polish. This does not mean that the variability in flint texture is not relevant when trying to measure use-wear micropolish, but it indicates that the three fine-grained flint varieties which we have used in our analysis are similar enough not to affect the texture of use-wear micropolish significantly.

The analysis of the four archaeological tools should be considered a preliminary trial to apply the discriminant potential of laser confocal microscopy to the analysis of cereal domestication. This was surely a very complex process, so a much larger sample of sickle elements is needed in order to gain relevant information on them. However, in the current state of our research, we thought it was important to carry out a first attempt and to evaluate the results. We have observed that the PPNA and the Middle PPNB sickle elements are placed in between the domestic and the wild experimental harvesting micropolish, while the Late PPNB element shows similar characteristics to the domestic cereal cutting micropolish. This classification corresponds roughly with the archaeobotanical data, as the PPNA cereals of Mureybet are morphologically wild (Willcox, 2008), while the first domestic cereals in the Middle Euphrates appear in the Mid PPNB levels at Tell Halula and became fully established in the Late PPNB levels (Willcox et al., 2009). These are promising results, suggesting that this method of micropolish quantification could characterize the process of cereal domestication. However, it is necessary to stress that the archaeological sample is still very small. If the study of a larger sample of archaeological tools offers data which are consistent with our preliminary analysis, this method of harvesting micropolish quantification could be used in other Near East sites to obtain a more detailed picture of the cereal domestication process.

The identification of the use-wear micropolish on the Natufian sickle element with the experimental tool for harvesting domestic cereal should be also considered as preliminary and tentative, as further analyses are needed to confirm this trend. Some indices of cereal domestication were identified in the Natufian levels at Mureybet, although these data are generally considered as dubious, as almost all the cereal remains at Epipalaeolithic sites in the Near East are wild (Nesbitt, 2002). As mentioned above, the presence of domestic cereals (3 grains of rye dated by AMS) has also been proposed by G. Hillman et al. (2001) for the Epipalaeolithic levels of Abu Hureyra, which is 20 km away from Mureybet. In this context, domestication during the Epipalaeolithic/Natufian in the area cannot be ruled out. However, the analysis of a larger sample is needed before going any further with this discussion.

5. Conclusions

We have shown that the use-wear micropolish resulting from harvesting wild cereals can be quantitatively distinguished from the one generated during the harvesting of domestic cereals. This is because wild cereals must be harvested when the plant is not completely ripe, while domestic cereals are most generally harvested when fully ripe. Thus, the different amount of humidity in the stems of the wild and domestic cereals when they are cut provokes micropolishes with different characteristics. Sampling of around six 500×600 μm areas across the polished surface seems to be enough for characterizing the micropolish texture. Taking measures from nine 100×100 μm subsamples from the previous areas works well. For the discrimination, choosing the more pertinent predictor parameters is crucial. It is also convenient to eliminate outliers from the measures of the subsamples. Lithic raw material variability is certainly an important source of variation in use-wear micropolish characteristics, but our study suggests that the variability between fine-grained flint varieties is not important enough to affect use-wear micropolish appearance. The degree of micropolish development, a relevant variable influencing use-wear micropolish variability, can be isolated if areas of micropolish with similar development are chosen for the quantitative analysis. However, we think that if we want use-wear micropolish quantification to be an alternative to the visual and qualitative identification of use-wear micropolishes, which is the standard method currently used, it is necessary to measure the degree of micropolish development, so as to build models of micropolish characteristics across the whole development process. We are now working in this direction.

This quantitative discrimination opens a line of research for studying the cereal domestication process. Sickle elements are present in most Natufian sites and are abundant in Early Neolithic sites, so, by using the proposed method, it is possible to distinguish the wild, domestic or intermediate nature of the harvested cereal for different geographical and chronological contexts. Moreover, this method would be able to address the variability in the state of the cereal when harvested which could exist within archaeological assemblages. Thus a more detailed knowledge of the process of cereal domestication would be possible, reinforcing and complementing data obtained through archaeobotanical analysis.

The preliminary analysis of four sickle elements coming respectively from Natufian, PPNA, Mid PPNB and Late PPNB contexts show, for the latter three, results which fit roughly with the archaeobotanical data. The Natufian sickle element showed traces which are similar to the experimental tool which was used for cutting domestic cereals. It is necessary to analyze a larger sample of archaeological tools before establishing clear conclusions. In any case, the discrimination of the experimental tools and the coherent grouping of the archaeological tools strongly suggests that confocal microscopy offers a valuable method for harvesting micropolish quantification, representing a valuable method to distinguish the state (either semi-green or ripe) in which cereals were harvested.

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