Evolution of Harvesting Technology: A Study of Diversity from Lithic and Botanical Remains in Neolithic Iberia (8th-7th millennium cal. BP)

María Barrera-Cruz [1], Oreto García-Puchol [1], Alfredo Cortell-Nicolau [2], Daniel García-Rivero [3]

1. PREMEDOC Research Group, Department of Prehistory, Archaeology and Ancient History, University of Valencia. Av. Blasco Ibañez 28, 46010 València, Spain. Email: MBC: maria.barrera@uv.es; OGP: oreto.garcia@uv.es
2. University of Cambridge. McDonald Institute for Archaeological Research, Department of Archaeology, University of Cambridge, Downing Street, CB2 3DZ, Cambridge, UK. Email: ac2320@cam.ac.uk
3. Department of Prehistory and Archaeology, University of Sevilla. Doña María de Padilla, s/n, 41004, Sevilla, Spain. Email: garciarivero@us.es

Abstract:

Pioneer farming groups arrived in the Iberian Peninsula in the first half of the eighth-millennium cal. BP. Since then, the spread of new populations continued, and the highly diverse material culture of the Neolithic has been interpreted as a reflection of multiple origins and as the regionalisation that followed. In the past few decades, the study of different lithic tools has served to explore cultural Neolithic patterns. In particular, changes in harvesting technology have provided helpful information about the diffusion of Neolithic groups, proposing possible transfers in technology or even cultural adaptation to agricultural changes as explanatory factors for subsequent shifts. Here, we investigate how the initial diversity in harvesting technology changes or remains over time and in different regions according to crop harvesting preferences. Also, we test whether the diversity of harvesting tool dynamics is related to technological factors. Thus, we characterise the crops, blade production, and harvesting tools associated with different areas from 7600 to 6400 cal. BP on a large and refined chrono-cultural scale. As a result, we confirm that using one sickle type is independent of the crop harvested, and at least until the Middle Neolithic, we observe that it does not limit the incorporation of the new agricultural system into the region. By including glossy and no glossy blade measurements in the analysis, we discard the effects of technological limitations as an obstacle for replicating the parallel type in those contexts where it is not documented. Moreover, we found significant differences between the coefficients of variation in blade samples inserted differently, likely influenced by the hafting system. Whenever possible, we discuss how this adapts to blade production. Incorporating a filter in selecting the sample in favour of dated assemblages made it possible to situate these patterns on a comparative scale of two hundred years through the entire time framework.

Keywords: Neolithic; Iberian Peninsula; Harvesting technology; Shafting constraint; Ecology

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1. Introduction and background

The initial spread of pioneer farmers in the Western Mediterranean was rapid, probably due to a maritime expansion with a pattern of discontinuous long-distance movement, the so-called leapfrog (Guilaine 2017; Isern *et al.* 2017; Zilhão 2001). Besides Bayesian chronological models and radiocarbon mapping (García-Puchol *et al.* 2017), routes have been tracked through pottery (Bernabeu Auban *et al.* 2009; Pardo-Gordó *et al.* 2020), lithic features (Cortell-Nicolau *et al.* 2021; Ibáñez-Estévez *et al.* 2017) and the recently incorporated DNA (Fernández *et al.* 2014; Olalde *et al.* 2019). During the early Neolithic, the archaeological record shows small-scale population with a mixed economy (Bernabeu Auban & Martí Oliver 2014; García-Rivero *et al.* 2019; Bernabeu-Aubán *et al.* 2017). Despite inter-regional contact not being discarded, the continuous movement of people and small-scale organisations could be linked to the parallel development of culture, often resulting in a certain degree of diversity in the archaeological assemblages of several areas (Pardo-Gordó *et al.* 2019). This variety could reveal variability in farming or livestock activities, pottery techniques and technology, settlement patterns, or even harvesting toolkits. After a few centuries of increasing population, around 5300 cal. BCE, we can detect a marked population trough (García-Puchol *et al.* 2021; Shennan 2013), and subsistence patterns seem to change (García-Rivero *et al.* 2022; Pérez-Jordà *et al.* 2017), along with the material culture. Here, we will study lithic technological and morphological patterns to compare and understand farmer behaviour against these movements and changes on the Iberian Peninsula.

1.1. Lithic's borderline in the Iberian Neolithic

During the past few decades, the study of lithic tools has served to explore Neolithic patterns, mainly applied to compare Mesolithic and Neolithic assemblages in the Iberian Peninsula (Alday Ruiz 2018; Cortell-Nicolau *et al.* 2020; García-Puchol 2005: 311-355; Juan Cabanilles 2008: 242-252), as well as to define the arrival and expansion routes. Thus, while variety in geometric microliths has pointed to the Northern Mediterranean as a clear expansion route (Cortell-Nicolau *et al.* 2021), variability in harvesting technology has provided additional evidence to follow the spread of at least two arrival waves of farmers groups, one linked to the use of La Marmotta sickle type, curved and with dented edge (Figure 1, A) and other with the use of La Draga reaping types, the L-shaped formed by a straight shaft, a transversal branch and a long flint blade inserted parallel to the haft (Figure 1, B), and the type of oblique insertion (Figure 1, C) (Ibáñez-Estévez *et al*. 2017; Mazzucco *et al.* 2020).

When one compares harvesting tools, at least two traits must be defined: the haft and the active edge. Although hafts are usually not well preserved due to their organic nature, we know some of them, are mainly preserved in waterlogged sites (Ibáñez-Estévez *et al*. 2017). In this regard, in order to classify them, both insertion type and haft type must be accounted for. Insertion types can refer to the angle and number of pieces introduced, while haft type refers to the morphology of the haft (Figure 1). In advance, this work will refer to the types as oblique-multiple (Figure 1, A), parallel (Figure 1, B) and oblique-simple (Figure 1, C).

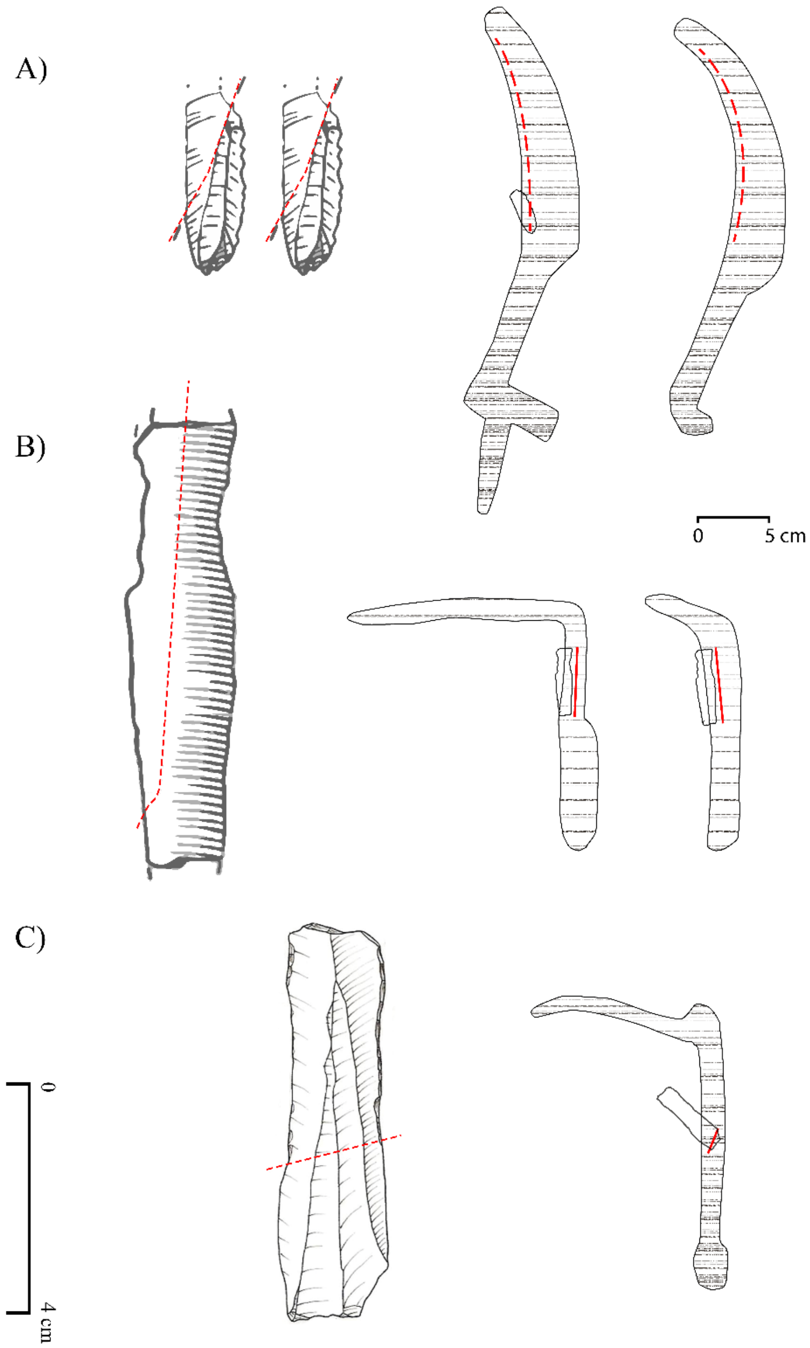

Figure 1. Variety in sickle types mentioned in the text. The red lines on the blades (left) indicate the limit between the active edge (where the cereal patina is) and the area inserted in the haft expected in each insertion type. The red line in hafts (right side in the image) indicates where the insertion slot for the blades is usually found, depending on the kind of haft. Source: Vectorized and modified images from several sources, including glossy blades from Castillejos (A), Chaves (B) and Casa Montero (C) (Castañeda 2021; Ibáñez-Estévez *et al*. 2017; Mazzucco *et al.* 2015; Mazzucco *et al.* 2020; Perales Barrón *et al.* 2015).

Figura 1. Variedad de tipos de hoz mencionados en el texto. Las líneas rojas en las láminas (izquierda) indican el límite entre el borde activo (donde está la pátina del cereal) y el área que se espera que esté inserta dentro del mango en cada tipo de inserción. Las líneas rojas en los mangos (lado derecho de la imagen) indican dónde suele encontrarse la ranura de inserción de las láminas, dependiendo del tipo de mango. Fuente: Vectorizado y modificado a partir de varios trabajos, incluyendo láminas con lustre de Castillejos (A), Chaves (B) y Casa Montero (C) (Castañeda 2021; Ibáñez-Estévez *et al.* 2017; Mazzucco *et al.* 2015; Mazzucco *et al.* 2020; Perales Barrón *et al.* 2015).

1.1.1. Harvesting technology in the light of evolutionary theory

Considering demic diffusion as the main force driving the Neolithic expansion in the Iberian Peninsula, the variability of harvesting techniques can be related to the initial spread points. However, in a scenario with several groups arriving and settling in different regions, the mechanisms governing such spread can vary as their tempos and modes overlap.

In this sense, variability in harvesting techniques can be helpful not only to correlate the initial diversity with different cultural groups arriving but also to suggest an adaptation process or, in case it is discarded, possible changes in cultural interactions since we have information about crop management for environmentally diverse regions.

Earlier attempts to relate harvesting techniques with environmental and crop variability tried to discard the relation between these factors. In Gassin *et al.* (2010), sickle types and plant remains were compared according to three major areas: the South-East of Spain with curved sickles of La Marmotta type; Catalonia, Languedoc, and Provence with most of the sickles being La Draga parallel type, and some others La Draga oblique-simple type; and Cantabrian Spain were cereals were harvested, at least in the beginning, without stone sickles. They distinguished four cultural phases for diachronic comparison according to pottery decoration techniques: *Impressa, Cardial ancien, Cardial récent/Epicardial ancien, and Epicardial récent/fin Néolithique ancien*. With a first general comparison between the vegetal and harvesting assemblages in the four phases, they did not detect a coincidence between differences observed in harvesting tools and cultivated plants.

The lack of relationship between sickle type used, region, and cereal harvested was partly accepted a few years later by Ibáñez-Estévez *et al.* (2017). Thus, they assumed that the distribution of the two main sickle types reflects “technical choices related to two different cultural traditions” (Ibáñez-Estévez *et al.* 2017: 359). This time, the discussion is focused on the appearance of the various technical traditions over time and space. By comparing the scenario every 500 years, they proposed the path and rhythms of several waves of Neolithic expansion in the Western Mediterranean. This hypothesis was taken up by Mazzucco *et al.* (2020), who incorporated archaeological contexts for the central and western Mediterranean, analysed the period for introducing the sickle types, and included identifying some sites where more than one sickle existed. There, they proposed another possible factor potentially related to the sickle type used: the harvester’s working capacity, where the maintenance of edge sharpness is essential (Nag *et al.* 1988). In this sense, while the La Draga type has been pointed as better adapted to more intensive harvesting since resharpening could be quickly done in the cultivation field, the Marmotta type does not seem to be designed for long harvesting sessions, since it is necessary to replace the blades to sharpen the edge (Mazzucco *et al.* 2018). Thus, in some areas, the growth in the number of parallel-inserted sickle types has been pointed out as a result of the adaptative character of the trait in a context where the agricultural system seems to change to the cultivation of larger fields between 5000-4800 cal. BCE. Thus, whereas the spread of the curved-sickle type seems related to the expansion phenomena, for parallel-hafted inserts some cultural, economic, and technical factors were proposed (Mazzucco *et al.* 2020).

However, harvesting one or more cereal taxa is just one of many functional factors that might be analysed. As in the vegetal remains, regarding the variability of the measures, we tried to discuss some questions apart from technology or raw material constraints. On this basis, this study aims to explore harvesting variation in a higher chronological resolution.

Mainly, we investigate (1) how the initial diversity in harvesting technology changes or remains similar after modifications in crop preferences already known (García-Rivero *et al.* 2022; Peña-Chocarro & Zapata 2012; Pérez-Jordà 2013: 127-146; Pérez Jordá *et al.* 2011). Two scenarios are possible: (a) sickle type changes along with crops or (b) sickle type remains after changes in crop assemblages. Also, (2) we tested whether harvesting tool dynamics are related to technological or raw materials factors. In this case, we test to determine whether differences in glossy blade measures are statistically significant between areas where changes in crop composition happened and areas where they did not.

Additionally, to gain a deeper understanding of the way harvesting technology is inserted in blade production or *vice versa*, we explore to what extent standardization in blade production allows the use of one or another sickle type. In this case, since all the glossy blades are inserted in a limited slot no matter the type of insertion, we expect similar shafting constraints between sickle types.

To do this, (1) we incorporate samples from 7600 to 6400 cal. BP, and in addition to glossy blades, (2) we include crop remains and (3) information about blade production from several sites that were first-hand studied (see details below). Continuities and discontinuities are grouped and discussed according to two hundred years-time bins. As a result, some questions about the relationship between shafting pressure, blade technology, and cereal crops can be addressed.

2. Materials and Methods

2.1. The sample. A diverse and robust dataset

This study includes the material culture of 29 Neolithic sites in the Iberian Peninsula (Figure 2). Specifically, we collected information about glossy blades and plant remains from published data, adding blade production details from some first-hand studied sites (see details in Table 1).

Figure 2. Sites included in the analysis. Colour indicates the Area, and shape indicates the data type available on every site.

Figura 2. Yacimientos incluidos en el análisis. El color corresponde al área y la forma al tipo de dato disponible en cada yacimiento.

Table 1. Sites included in the analysis. Contextual information and time-window as specified in the text. Counts of the lithic sample: n total; no glossy and glossy blades by insertion type. Vegetal information is available (x). In all cases, vegetal data was collected from bibliography sources. This table includes the vegetal column only to indicate which context includes cereal data. In this sense, the details on the totality of the sites with available plant data and those on the vegetal bibliography are reserved for Figure 3. (*) Data published from all the units is merged. In these cases, crop remains are recovered for all the site sequences (VIII to VII millennium cal. BCE). In total, 1005 blades from Cova de l'Or (693), Mas d'Is (77), Murciélagos de Zuheros (199), Cueva de la Dehesilla (35), and Cueva de Nerja (1) have been firsthand measured (95% of total) including glossy (55) and no polished blades (950).

Tabla 1. Yacimientos incluidos en el análisis. Información contextual y datos cronológicos de acuerdo con el tratamiento recibido. Cuantificación de la muestra lítica: *n* total; Láminas sin lustre y láminas con lustre según el tipo de inserción. Información vegetal disponible (x). En todos los casos, los datos vegetales se recogieron de fuentes bibliográficas. En esta tabla se incluye la columna vegetal solo para indicar qué contexto incluye datos de cereales. En este sentido, tanto los detalles sobre la totalidad de los sitios con datos vegetales disponibles como los de la bibliografía utilizada se reservan para la Figura 3. (*) Indica que se fusionan los datos publicados de todas las unidades. En estos casos se recuperan restos de cultivos para toda la secuencia del sitio, tal como aparece reflejado en las publicaciones originales (VIII al VII milenio cal. BCE). En total, 1005 láminas procedentes de Cova de l'Or (693), Mas d'Is (77), Murciélagos de Zuheros (199), Cueva de la Dehesilla (35) y Cueva de Nerja (1) han sido medidas de primera mano (95% del total), incluyendo láminas con pátina (55) y sin ella (950).

						Insertion					
Area	**Site**	**Contextual unit**	**Time-window**	***n* total**	***n* No glossy blades**	Oblique multiple	Parallel	Oblique simple	sn	**Vegetal**	**Blade reference**
Ebro	Chaves	Ia	7400-7200	4	0	0	3	0	1		(Cava Almuzara 2000; Domingo Martínez 2014; Mazzucco *et al.* 2015; Utrilla Miranda & Laborda Lorente 2018)
			7200-7000								
		Ib	7600-7400	5	0	0	4	0	1		
			7400-7200								
	Mendandia	II	7600-7400	2	0	0	2	0	0		(Alday Ruiz *et al.* 2012)
			7400-7200								
	Atxoste	IIIb1	7200-7000	3	0	0	3	0	0		(Alday Ruiz *et al.* 2012)
Interior	Casa Montero		7400-7200	2	0	0	0	2	0		(Castañeda 2021)
			7200-7000								
	La Lámpara	Hoyo 1	7000-6800	1	0	0	0	1	0	x*	(Rojo-Guerra *et al.* 2008: 505-506, 508, 514, 515)
		Hoyo 9	7200-7000	1	0	0	0	1	0		

			7400-7200								
	La Revilla	E12	7200-7000	1	0	0	1	0	0	x*	
		E13	7200-7000	1	0	0	1	0	0		
	La Vaquera	I	7400-7200								
			7200-7000	5	0	0	1	4	0	x	(Estremera 2003: 150-156, 227-230; Gibaja-Bao *et al.* 2012)
			7000-6800								
		II	6800-6600	1	0	0	1	0	0	x	
			6600-6400								
Northeast	La Draga	II	7200-7000	10	0	0	7	3	0	x	(Bosch *et al.* 2000: 202-203; Bosch *et al.* 2011: 96; Gibaja-Bao & Palomo 2006; Palomo *et al.* 2011)
		I	7000-6800								
	Guixeres de Vilobí	Ambito1	7600-7400	1	0	1	0	0	0		(Gibaja-Bao *et al.* 2018; Oms *et al.* 2021)
		Ambito2	7400-7200	1	0	1	0	0	0		
	Sant Pau del Camp	Level IV base (silos 1, 2)	7400-7200	1	0	0	1	0	0	x	(Borrell & Gibaja-Bao 2012)
			7200-7000								
		Level IV base (silos 9, 10)	7600-7400								
South	Castillejos	I	7400-7200								
			7200-7000	2	0	2	0	0	0	x	(Perales Barrón *et al.* 2015)
			7000-6800								
	Dehesilla	ENB	7200-7000	25	24	1	0	0	0	x	(García-Rivero *et al.* 2018; García-Rivero *et al.* 2021) and unpublished measures (database for blank blades)
		MNA	6800-6600	10	9	1	0	0	0	x	
			6600-6400								

	Doña Mencia		7000-6800	2	0	1	0	0	1	x	(Martínez-Sánchez & Vera-Rodríguez 2017: 61 y 64; Gibaja-Bao & Mazzucco 2017)
			6800-6600								
	Nerja	EN	7600-7400	1	0	1	0	0	0	x	Unpublished
			7200-7000								
	Zuheros	NA	7200-7000	92	84	8	0	0	0	x	(Carvalho *et al.* 2012; González Urquijo *et al.* 2000; Vera-Rodríguez 1997) and unpublished (dababase for blank blades)
		NB	7000-6800	107	105	2	0	0	0	x	
			6800-6600								
Xúquer	Benàmer	II	7600-7400	1	0	1	0	0	0		(Torregrosa-Giménez *et al.* 2011: 192-212)
		III	6600-6400	3	0	0	3	0	0		
	Mas d'Is	VIb	7600-7400	21	13	8	0	0	0	x	(Cortell-Nicolau & García-Puchol 2020; Garcia-Puchol *et al.* 2011) and unpublished (database for blank blades)
		VIa	7400-7200	56	51	5	0	0	0		
	Or	NIa	7400-7200	581	555	14	5	0	7	x	(García-Puchol 2005: 195, 199, 209; Gibaja-Bao *et al.* 2010; Juan Cabanilles 2008: 108-127, 204-215) and unpublished (database for blank blades)
			7200-7000								
		NIb	7400-7200	112	109	1	2	0	0	x	
			7200-7000								

In general, samples from mixed/merged or not dated contexts were not considered in the selection, except for archaeobotanical remains from Ambrona Valley, since, despite being published without chronological details, it is the testimony of a singular crop in the region. The sample covers 1.200 years of Neolithic occupation over the Iberian Peninsula's North, Northeast, Interior, East, and South.

2.1.1. Levels, dates, and blades

This work analyses 1052 blades (blank blades: 950; glossy blades: 102) located in 30 contextual units from 18 archaeological sites (see Table 1), where "contextual unit" refers to the minimum unit of analysis. Due to the diverse nature of the sample, we distinguished two situations: (1) when the glossy blade belongs to a dated stratigraphic unit and details were available, and (2) when pieces do not belong to a dated stratigraphic unit, or rather details were not published, but they are included into a general context chronoculturally defined, thus period or phase. In the first case, and whenever possible, we included dates from the same stratigraphic unit where the piece was found in the analysis. In the second, pieces have been included along with the radiocarbon data available for the entire chronocultural phase defined (see supplementary material for more details about the sites sampled). Dates used in the analysis are included in Supplementary Table 1.

In addition, to be considered in the sample insertion type, details and metric information (scaled photography or figure) need to be available in the bibliography. In this sense, glossy presence and insertion mode details were already confirmed and well described in the literature (see bibliography source details in Table 1). From this, we have proceeded to vectorize all assemblage of glossy blades.

Whenever possible, to understand how glossy blades are incorporated into blade production, we compared polished blade measures with the measurement of the blade production assemblage. In this case, the study includes 1005 additional blade measurements from the Southern and Eastern Iberian Peninsula to summarize the blade measurements' regional trends.

2.1.2. Sites, dates, and cereals

About the botanical record, this study uses only domestic (harvested) taxa, specifically cereals. Part of the difficulty is that crop remains are not always preserved or available. In some cases, details about the unit or layer where the seeds and fruits samples were located are not published, and it becomes an issue to work with it in sites where occupations are continuous and long-term. Thus, apart from those units where both glossy blades and plant remains were available ("x" in the column Vegetal of Table 1), vegetal samples from additional dated contexts have been included to illustrate the evolution of crop exploitation and to be related to lithic results in the discussion. They total 21 new contextual units from 12 additional sites (Figure 3).

Regarding the chronological location of these remains, and unlike the glossy blades included in the analysis as single items, interpretations of the crops remaining from a cultural unit are generally made as a package.

2.2. Methods

All analyses were developed using R statistical language (R Core Team 2022). Scripts and data are included in the supplementary material to promote a fully reproducible study.

2.2.1. Grouping the sample. Time-bins and regional clustering

We studied variation between connected assemblages from synchronic and diachronic scales. Firstly, we cluster the sites according to the region where they are located (see column "Area" in Table 1 and Figure 2). We seek to respond to whether the samples found in relatively similar orographic and ecological environments are more similar among them as opposed to the most distant ones.

In the diachronic approach, to split the archaeological information into chronologically consistent samples, we applied the following criteria for the selection of radiocarbon dates (Bernabeu-Auban 2006; Zilhão 2001; 2011): (1) pieces with standard deviation ≥ 100 were discarded. (2) Short-lived dates were selected over large-lived dates; however, when impossible, we included long-lived dates to avoid losing representativeness in specific regions or periods. Finally, (3) we prioritise radiocarbon data from the layer or unit where the glossy blade was precisely located. If this was impossible, we selected radiocarbon dates from units or layers culturally consistent with the original layer or cultural unit where the blade was coming from. In these cases, if we took more than one radiocarbon data, (4) we test for their internal consistency with the “rcarbon” package (Crema & Bevan 2020).

When the p-value indicated that radiocarbon dates were not consistent with the same chronological event (p-value ≤ 0.05), dates were rearranged according to the sequence details (see decision-making details for these cases in the Supplementary material). Finally, (5) we calibrate date results using the IntCal20 calibration curve. For defining our temporal phases, (6) we selected a two-hundred-year time range. To assign each archaeological site or layer into one or more of these chronological phases, we took as a reference the probability mass for each date calibrated at two-*sigma*. We assigned any site/layer to a specific phase if at least 25% of the probability mass fell in that phase (Bernabeu-Aubán *et al*. 2017). We included the sample associated with the date in every time phase where the date fulfils the percentage condition.

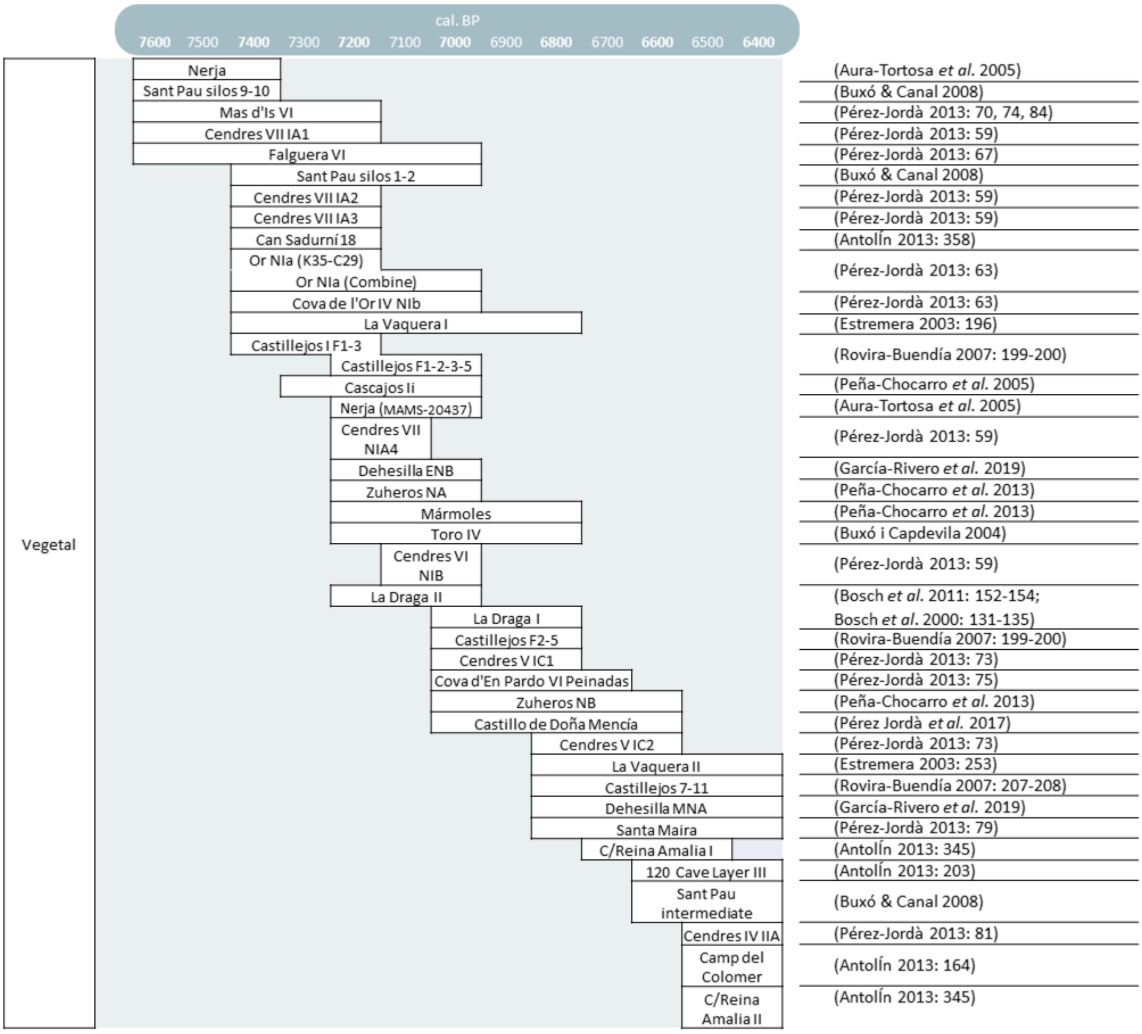

Figure 3. Cereal remains detected in the different contexts ordered according to 200 years of time phases. In all cases, vegetal data was collected from bibliographic sources.
Figura 3. Restos cereales detectados en los distintos niveles ordenados de acuerdo con ventanas temporales de 200 años. En todos los casos los datos vegetales fueron recogidos a partir de bibliografía.

2.2.2. Testing differences in blade measures

To insert blades in the handle slot, sometimes the length of the blade is modified by breaking or retouching the extremes of the blade before being inserted (Gibaja-Bao *et al.* 2007; 2012; 2017; Ibáñez-Estévez *et al.* 2017; Mazzucco *et al.* 2020), especially in composed edges. Therefore, due to the high fragmentation index of blade production, it is not easy to determine whether the fragmentation is due to intentional or accidental causes. Because of this, we used width to compare the measurement of the blade between different chronological contexts and regions.

We compare distributions visually and perform the appropriate statistical test according to the sample type to test whether assemblages were similar through time and space. Thus, to check if the continuous variable "width" differs across samples, we need to check whether the sample is normal distributed and whether the samples that will be compared have equal variance. To confirm normal distribution, we used the Shapiro-Wilk Normality Test, and to determine the homogeneity or heterogeneity of variances, we used the test of Bartlett (for parametic cases) and Lévene (for non-parametric). Then, we run Student's (parametric and equal variances) or Welch's t-test (parametric but unequal population variances) and Mann-Whitney test (non-parametric) as two-sample tests and Games-Howell (parametric but no equal variance) and Dunn test (non-parametric) as pairwise comparison tests (see a summary of test in Table 2). For a clear representation of the distributions compared with the results of the tests, we used the R package "ggstatsplot" (Patil 2021).

Table 2. The test was carried out on the blades' width measurement.
Tabla 2. Pruebas llevadas a cabo sobre la medida ancho laminar.

Function		Type	Equality of variance	Test
Verify normality				Shapiro-Wilk Normality Test
Verify homoscedasticity		Parametric		Bartlett test
		Non-parametric		Levene test
Hypothesis test	Two-samples test	Parametric	True	Student's test
		Parametric	False	Welch's t-test
		Non-parametric		Mann-Whitney test
	Pairwise comparison test	Parametric	False	Games-Howel test
		Non-parametric		Dunn test

2.2.3. Ecological distance from crop remains

Given the high diversity in the agricultural strategies in our framework, we decided to search for general changes in the crop composition through area and time windows. Thus, we used Rényi diversity profiles (Kindt & Koe 2006: 60), which ranks community profiles according to diversity and species distribution.

The interpretation of the Rényi profiles is as follows. First, the shape of the profile is an indication of evenness. The horizontal profile indicates that all species have the same evenness. Also, some information is provided for the values in different positions for the scaling parameter [α]: (1) the starting place indicates the species richness; the higher the initial position, the more diverse the community is. However, if profiles cross over, it is impossible to order the communities by diversity. (2) The profile value for α = infinity provides information about the dominant species; higher profiles have a lower proportion of the dominant species (Kindt & Koe 2006: 60-65). (3) The value for α = 1 is the Shannon diversity index, and (4) α = 2 is the logarithm of the reciprocal Simpson diversity index.

3. Results

According to the chronostratigraphic information, sites and sickle type are displayed in line with results from previous works (Gibaja-Bao *et al.* 2017; Ibáñez-Estévez *et al.* 2017; Mazzucco *et al.* 2020) (see Figure 4). Along with the area clusters, the two-hundred-year time window becomes helpful in comparing the evolution between lithic and vegetal remains.

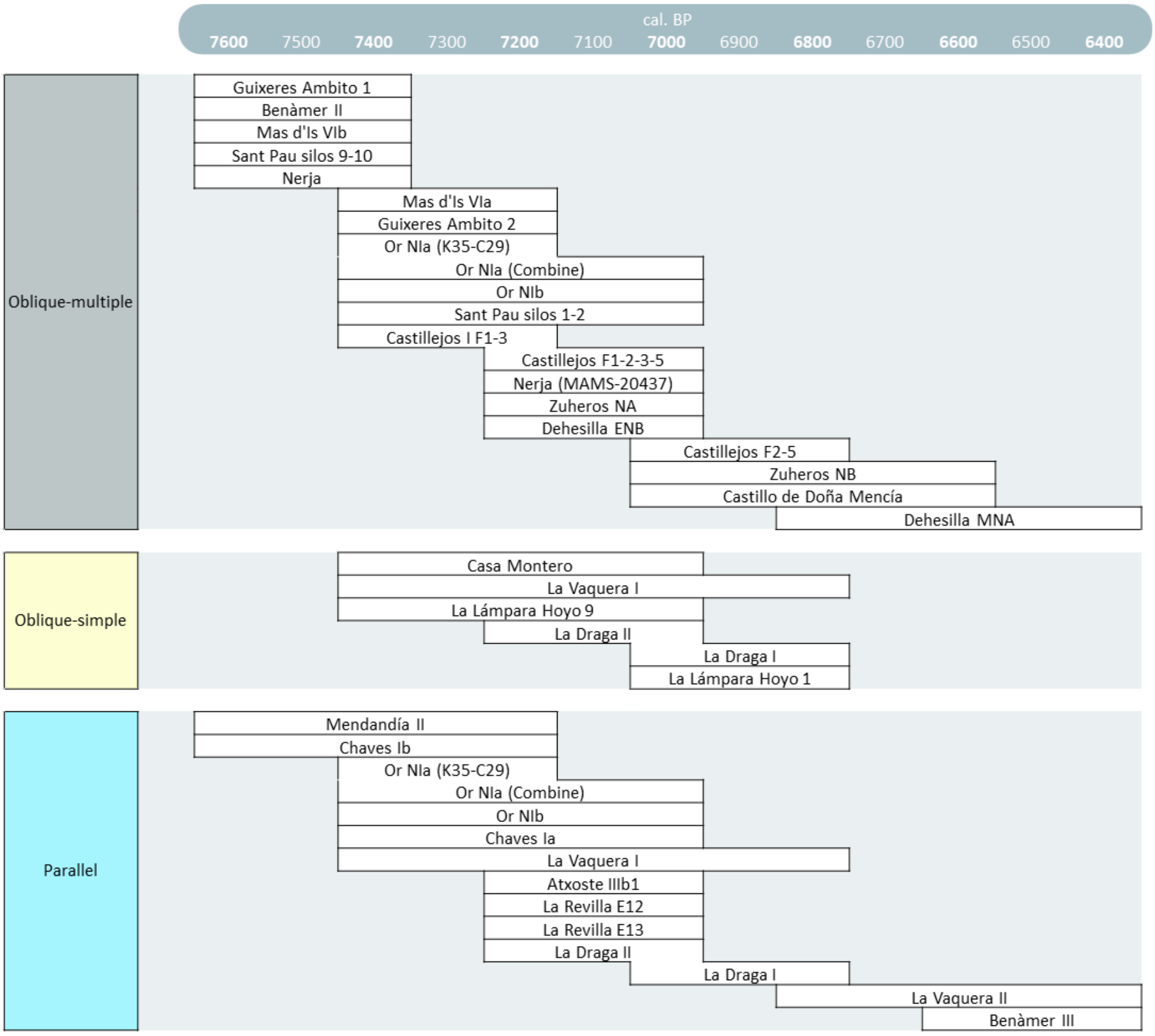

Figure 4. The insertion type detected in the different contexts was ordered according to the phases of 200 years. References are displayed in Table 1.
Figura 4. Tipos de inserción detectados en los distintos niveles ordenados de acuerdo con ventanas temporales de 200 años. Las referencias se muestran en la tabla 1.

3.1. Blade technology and insertion type measurement through clusters

Overall, measurements from blades selected to be inserted in sickles seem more similar between closer regions. Games-Howell test revealed that glossy blade measures from the

Northeast and Interior areas are statistically different from those in Xúquer and South (Figure 5).

When we compare samples attending to the insertion mode, differences are statistically significant between parallel-inserted blades from Xúquer and the Interior area (see Figure 6). In this scale, differences between oblique-multiple inserted blades could not be proved because of the sample size in the Northeast area (n = 2).

If we compare glossy blade measures between the South and Xúquer areas, the Student's t test discards significant differences between the oblique multiple inserted type (Figure 7) with a p-value = 0.84.

Because Xúquer has the parallel-inserted type and the oblique-multiple type, we tested whether parallel-inserted blade measures in Xúquer differed from the oblique-multiple type located in the South. As a result, the Student's t-test reveals significant differences only when the sample's parallel from Benàmer III was included, with $p = 0.03$ (Figure 8). There is no significant difference in excluding Benàmer III (6600-6400 cal. BP) ($p = 0.36$).

We detected some exciting patterns by focusing on integrating glossy blade measures in blade production. On the one hand, according to the Mann-Whitney test's results ($p = 0.01$), in the South, the widest blades were selected among the blade production to be inserted in the sickles (Figure 9) while, on the other hand, in Xúquer glossy blades' width distribution is the same as the total blades' width distribution (Figure 10), at least until 6600 cal. BP, when Benàmer III breaks that trend ($p = 0.02$). Finally, the Mann-Whitney test shows statistically significant differences between the total laminar production measurements of both areas ($p = 0.00006$) (Figure 11), even with Benàmer III excluded (Figure 11, bottom).

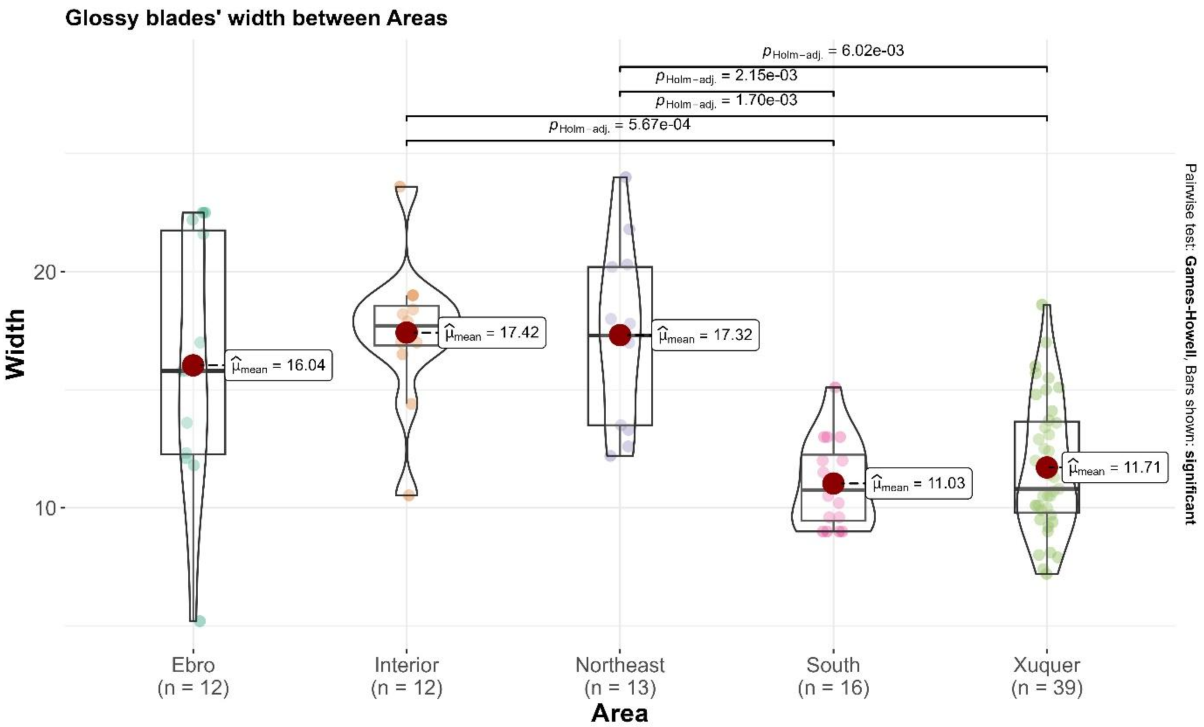

Figure 5. Box and violin plots from blades' width ordered by area. Based on the pairwise test, bars connect only samples statistically differently (see p-values above the bars).

Figura 5. Diagramas de caja y violín a partir del ancho laminar agrupado por área. Las barras conectan únicamente muestras estadísticamente diferentes según la prueba por pares realizada (consultar p-valores sobre las barras).

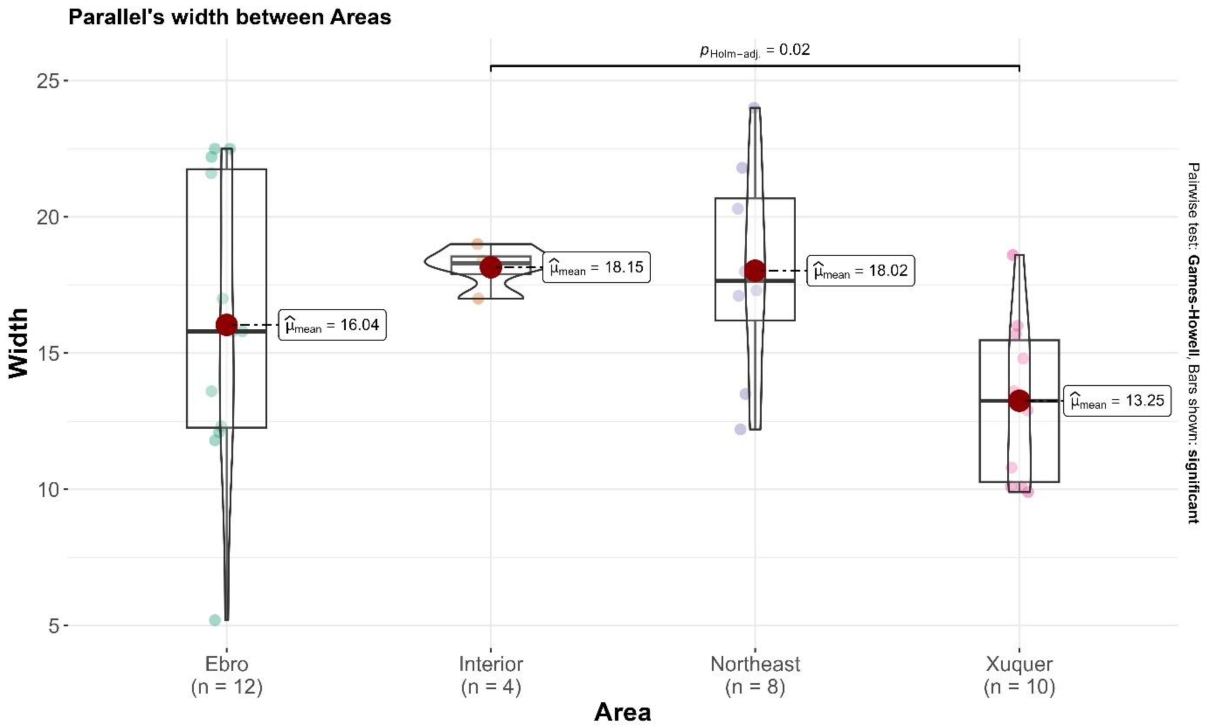

Figure 6. Box and violin plots from parallel-inserted blades' width ordered by area. Based on the pairwise test, bars connect only samples statistically differently (see p-values above the bars).
Figura 6. Diagramas de caja y violín a partir del ancho de láminas insertas en paralelo agrupado por área. Las barras conectan únicamente muestras estadísticamente diferentes según la prueba por pares realizada (consultar p-valores sobre las barras).

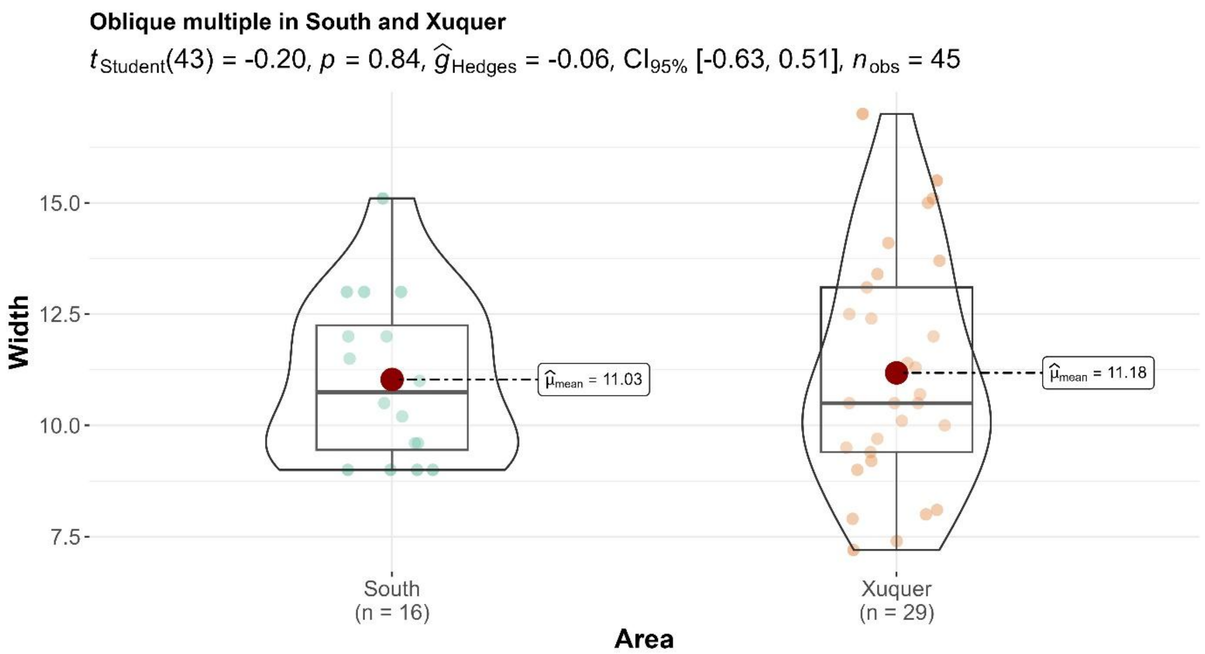

Figure 7. Box and violin plots from oblique multiple inserted blades' width located in South and Xúquer ordered by area. Statistical details are included at the top (t-test results).
Figura 7. Diagramas de caja y violín a partir del ancho de láminas insertas en diagonal en el Sur y el Xúquer agrupado por área. Los detalles estadísticos se incluyen en la parte superior (resultados de la prueba t.test).

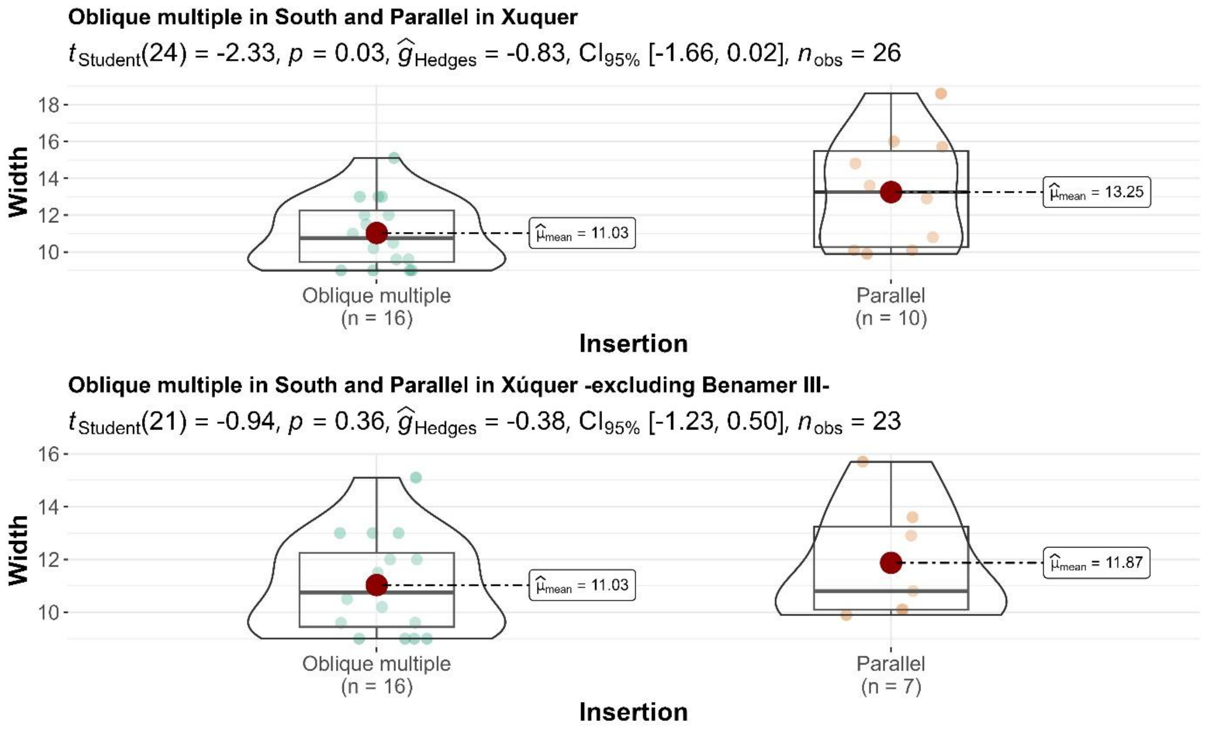

Figure 8. Box and violin plots from oblique multiple inserted blades' width (South) and parallel-inserted type (Xúquer) including (at the top) and excluding (at the bottom) Benàmer III. Statistical details are included at the top (t-test results).

Figura 8. Diagramas de caja y violín a partir del ancho de láminas insertas en diagonal (Sur) y paralelo (Xúquer) incluyendo (arriba) y excluyendo (abajo) Benàmer III de la muestra. Los detalles estadísticos se incluyen en la parte superior (resultados de la prueba t.test).

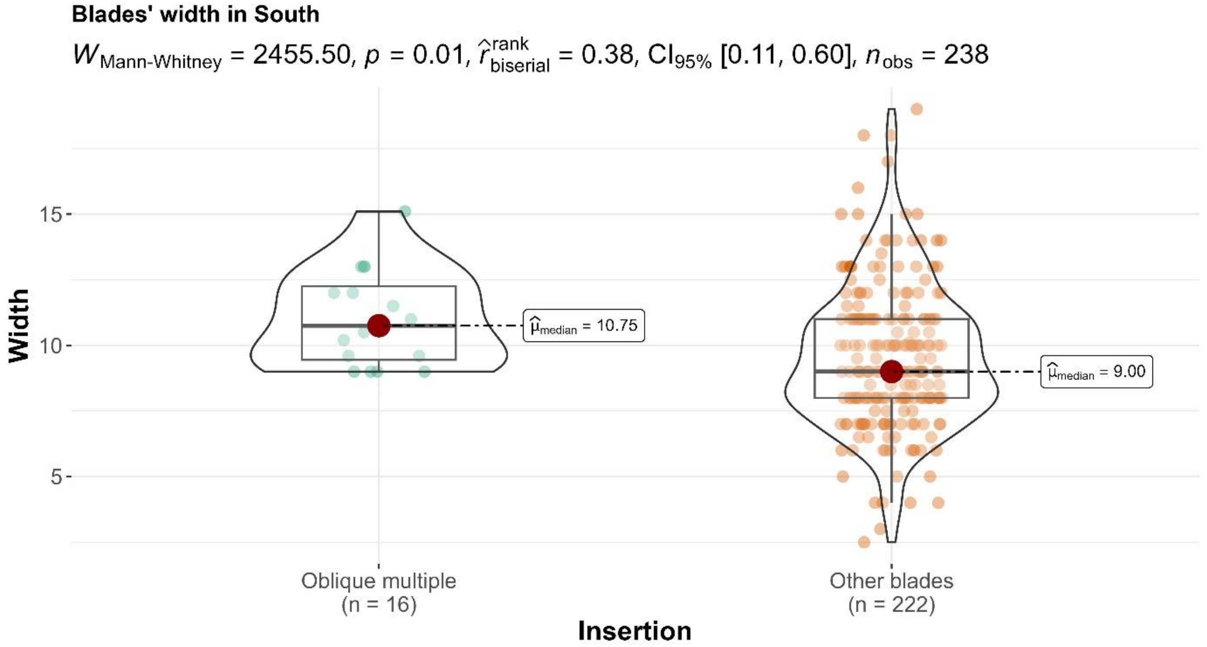

Figure 9. Box and violin plots from the blades' width are in the south. Statistical details are included at the top (t-test results).

Figura 9. Diagramas de caja y violín a partir del ancho de láminas insertas en diagonal ubicadas en los yacimientos del área Sur. Los detalles estadísticos se incluyen en la parte superior (resultados de la prueba t.test).

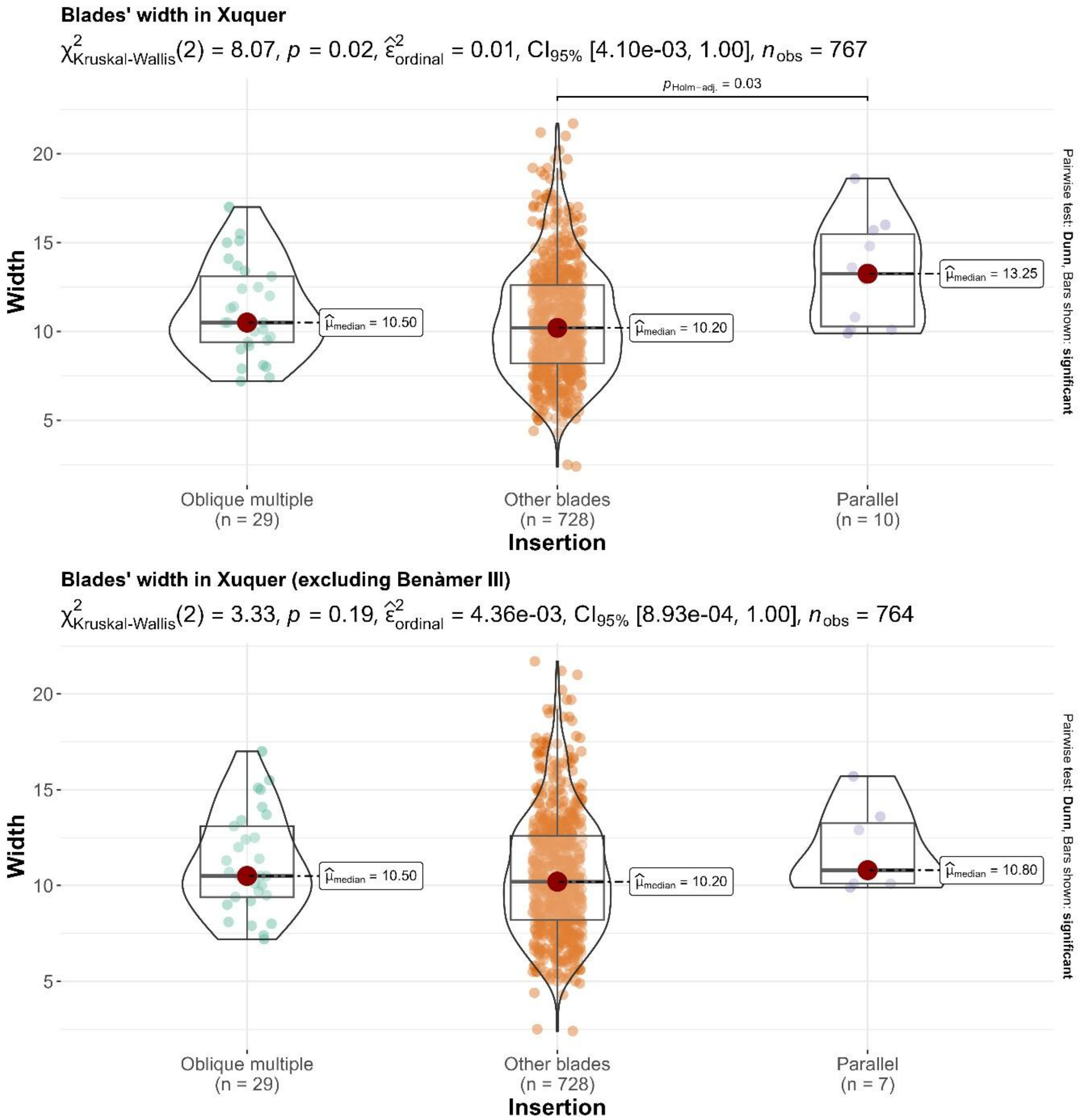

Figure 10. Box and violin plots from blades' width located in Xúquer. Statistical details are included at the top (t-test results).
Figura 10. Diagramas de caja y violín a partir del ancho de láminas insertas en diagonal ubicadas en los yacimientos del área Xúquer. Los detalles estadísticos se incluyen en la parte superior (resultados de la prueba t.test).

Once we know the mean and median differences, we compare the variance in general measures between types of insertion with a Levene test. As a result, the variance of parallel assemblage is different for oblique-multiple (F = 11.227, $p = 0.001$) but not with the oblique-simple type (F = 1.5692, $p = 0.21$).

3.2. Agricultural strategies and insertion types

Figure 12 reconstructs agricultural traits across time and areas through bar plots and Rényi profiles. While the former provides information about taxa composition, the latter informs us about diversity and evenness.

According to the sampled sites, crop diversity is generally higher during the first four hundred years of the Neolithic occupation (see colours in the bar plots of Figure 12). But within that initial diversity, some regions share cereal preferences, as in the South and Xúquer regions versus the Interior and Northeast. The crop preferences later include a higher presence of naked taxa in general.

Regarding the Rényi profiles, contours tend to intermediate shapes in the first centuries. In Xúquer, the mostly horizontal trend in the form indicates that species are generally equally represented. In 7400-7200 cal. BP, with a more significant sample, values in α for Northeast, Xúquer, and Interior areas cross over, suggesting similar diversity trends. Ebro and South remain below the previous one, but the shape of the South is more similar to the previous ones and partially overlaps with them. In the first case, the information is provided for a single site, so although we now know hulled crops are predominant, this draws an unstable curve. Later, high-curved shapes are incorporated in the Northeast (7200-6800 cal. BP) and the South (6800-6400 cal. BP) areas, revealing the presence of dominant species in the sample. Thus, in the last time window, South and Northeast profiles describe similar agricultural strategies despite using a different harvesting tool. Xúquer superposition does not allow differentiating the system from any of the current trends.

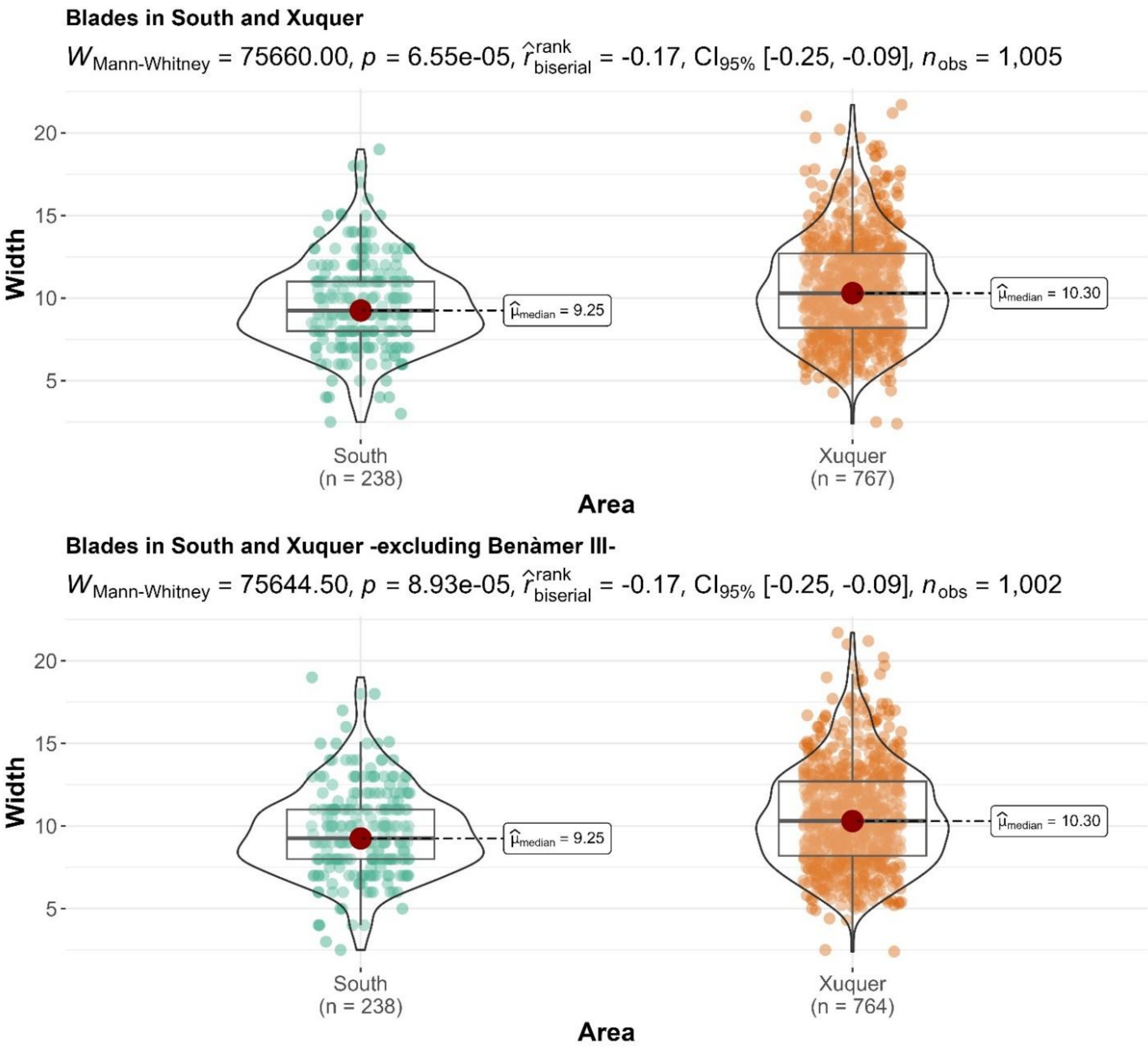

Figure 11. Box and violin plots from blades' width located in Xúquer and South. Statistical details are included at the top (t-test results).
Figura 11. Diagrama de caja y violín a partir del ancho de láminas ubicadas en Xúquer y Sur. Los detalles de los resultados estadísticos se incluyen en la parte superior (resultados de las pruebas t-test).

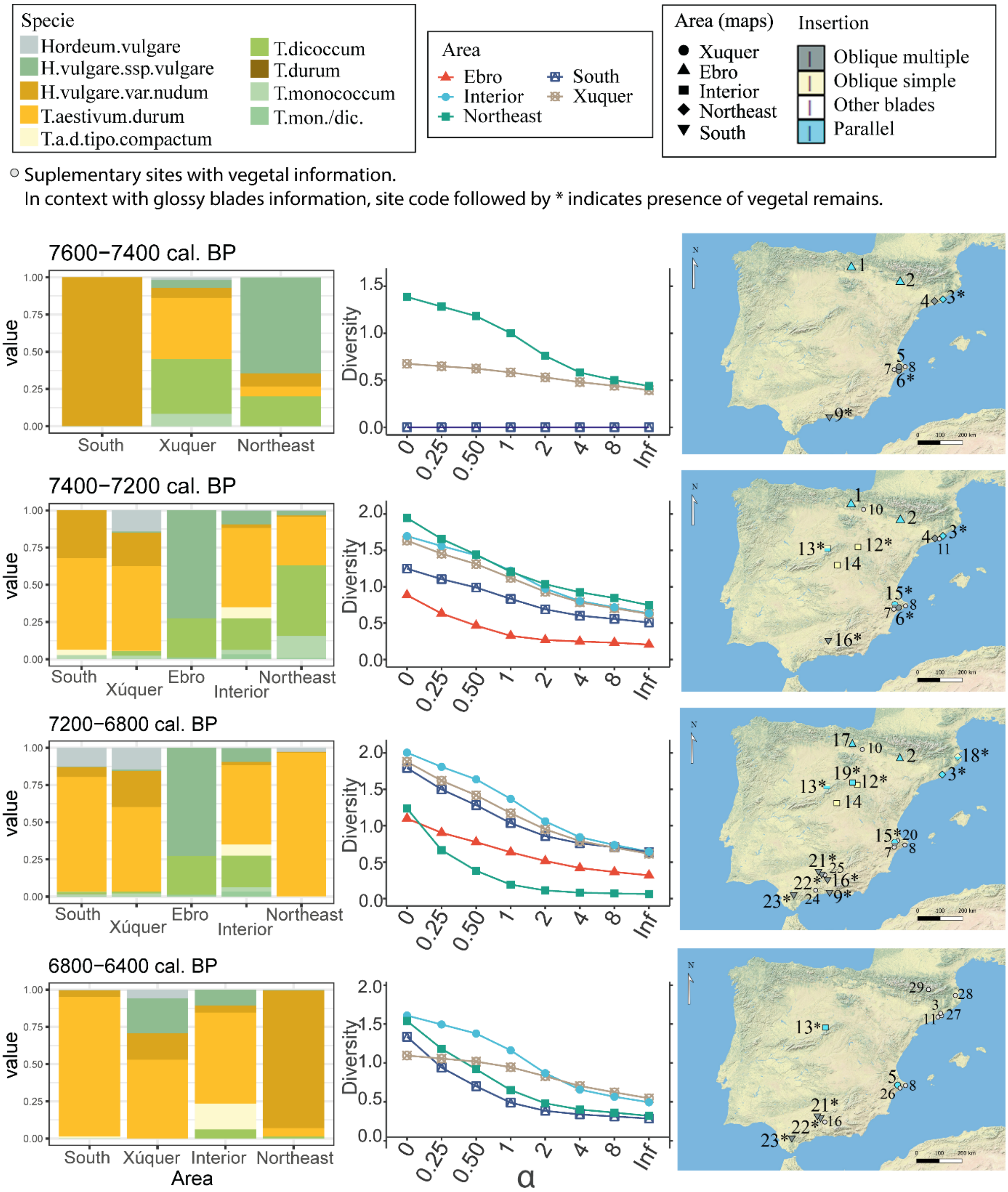

Figure 12. Reconstruction for agricultural traits performed ordered by area and 200 years-time phases. In cereal bar plots, axis y reflects proportions, greenish colours refer to hulled taxa, and yellowish refer to free-threshing cereals. Sites: 1) Mendandia; 2) Cueva de Chaves; 3) Sant Pau del Camp; 4) Guixeres de Vilobí; 5) Benàmer; 6) Mas d'Is; 7) Falguera; 8) Cova de les Cendres; 9) Cueva de Nerja; 10) Los Cascajos; 11) Can Sadurní; 12) La Lámpara; 13) La Vaquera; 14) Casa Montero; 15) Cova de l'Or; 16) Los Castillejos de Montefrío; 17) Atxoste; 18) La Draga; 19) La Revilla; 20) Cova d'En Pardo; 21) Murciélagos de Zuheros; 22) Castillo de Doña Mencía; 23) Cueva de la Dehesilla; 24) Cueva del Toro; 25) Mármoles; 26) Santa Maira; 27) Calle Reina Amalia; 28) Cueva 120; 29) Camp del Colomer.

Figura 12. Reconstrucción de rasgos agrícolas representados ordenados por área y según ventanas de 200 años. En los diagramas de barras de cereal, el eje y refleja proporciones y los colores verdosos hacen referencia a taxones vestidos, mientras que los amarillentos se refieren a taxones desnudos. Yacimientos: 1) Mendandia; 2) Cueva de Chaves; 3) Sant Pau del Camp; 4) Guixeres de Vilobí; 5) Benàmer; 6) Mas d'Is; 7) Falguera; 8) Cova de les Cendres; 9) Cueva de Nerja; 10) Los Cascajos; 11) Can Sadurní; 12) La Lámpara; 13) La Vaquera; 14) Casa

Montero; 15) Cova de l'Or; 16) Los Castillejos de Montefrío; 17) Atxoste; 18) La Draga; 19) La Revilla; 20) Cova d'En Pardo; 21) Murciélagos de Zuheros; 22) Castillo de Doña Mencía; 23) Cueva de la Dehesilla; 24) Cueva del Toro; 25) Mármoles; 26) Santa Maira; 27) Calle Reina Amalia; 28) Cueva 120; 29) Camp del Colomer.

4. Discussion and conclusions

4.1. Early Neolithic farming diversity and social network

Diversity in agricultural strategies and harvesting technology seems stable from 7600 to 7200 cal. BP (see intermediate shapes in Rényi profiles and the presence of different sickle types for this time across the space in Figure 12). Here, although diversity in the crop by region is variable, the crop pool is more diverse than in the Middle Neolithic (*c.* 6800 cal. BP) in all the cases. Meanwhile, the lack of decreasing tendencies in diversity in harvesting technology does not correspond to changes in crop features. In this point, some factors must be pointed out to understand variability in crop and harvesting technology at that chronology.

In the Early Neolithic context, the wider crop diversity is often related to an intensive and self-sufficient agricultural system (Bogaard 2004; Halstead 1989; Pérez-Jordà *et al.* 2017), which is linked simultaneously to a small-scale settlement model. At the same time, the multiple origins of the groups who inhabited the peninsula at this time could support the differences noted between regions.

But despite that initial diversity, some regions share cereal (mainly naked taxa versus a more significant presence of hulled) and harvesting preferences (oblique-multiple -probably curved haft- versus L-shaped), as in the case of the South and Xúquer regions versus the Interior and Northeast (see 7400-7200 cal. BP in Figure 12). However, this trend is sometimes porous since Xúquer presents a higher scope of hulled taxa and the use of harvesting technology alternative to the oblique-multiple type.

Furthermore, to understand why the Xúquer area has a specific diverse character, one needs to think of different scenarios. One option is related to the multiple origins of the groups studied (Gibaja-Bao *et al.* 2017; Mazzucco *et al.* 2020; Pardo-Gordó *et al.* 2019); and another one could be related to how the social networks of this area allowed sufficient levels of exchange of information to acquire certain cultural traits not present in the south (if we think about the presence of hulled taxa or parallel insertion blades) or in the north (if we think about curved sickles). Regardless of how diverse the origin of these populations was, considering the small-scale organisation suggested for these populations in the first centuries of the Neolithic people, one can expect certain limitations in transmitting information if thinking about local interaction networks. Thus, the last possibility would need to be confirmed by analysing the social networks of these groups according to additional lithic traits.

4.2. Parallel-inserted sickle type in the Middle Neolithic. Advantage or replacement?

From 7200 cal. BP, changes in the Rényi profiles in the Northeast first and later in the South found different responses in the harvesting technology. In the Northeast, La Draga site leads to change, where oblique-simple and parallel sickle types are present. Also, oblique-multiple types disappear in the area. The South profiles define a less variable agricultural system where free-threading is the most abundant taxa. This trend has been especially marked in the last four hundred years; however, groups have continued to use the curved sickle type in this area. Trends in Rényi profiles are consistent with previous studies (Pérez-Jordá *et al.* 2017) that detected a notable reduction in the taxonomic diversity of harvested cereals shaped in a consolidation of two naked taxa as the main crop, *Triticum aestivum/durum* and *Hordeum vulgare* subs. *nudum*.

Concerning the continuous decrease of diversity, according to some studies (de Vareilles *et al.* 2022), the effect of movement of the population can affect the original crop variety in such a way that once the population arrives, diversity can be (1) maintained, maybe as an environmental risk-countering mechanism, or (2) reduced, due to multiple factors as the founder effect or influences of the environment; however, in this chronology, this reduction has been related to a change in the agrarian model from an intensive to an extensive one (Bogaard 2004; Halstead 1996; Pérez-Jordá *et al.* 2017).

In the relationship between harvesting tools and the management of extensive crops, the new agricultural model involves exploiting larger soil areas, and here, the easy reshaping of the parallel sickle edge has been pointed as an advantage (Mazzucco *et al.* 2018; 2020). Here, one could wonder about the maintenance of oblique-multiple sickle type in the South. Even though the fitness of the parallel-inserted sickle type could benefit this new agricultural system or *vice versa*, the ancient trait "oblique-multiple serrated sickles" was kept in the South over time, even when this new agricultural system was performed. However, reshaping is not the only significant feature in harvesting an extensive field: experimental studies proved that the interaction between the shape of the sickle and the position of insertions is decisive to the cutting capacity of the sickle and, specifically, that the use of a curved haft with the edge composed for obliquely set inserts increases the cutting capacity of the tool (Astruc *et al.* 2012). In this way, using the curved sickle would also mean the application of a tool adapted to the harvest of large areas of the field.

In Andalucía, the crop transition was detected for the first time in the Middle Neolithic A period (MNA) at Dehesilla cave (García-Rivero *et al.* 2019; 2022), where groups also used oblique-multiple type (probably inserted in curved sickle type). Were these populations not aware of this technology? Aside from differences in the network of cultural relationships, a few issues could limit the use of one or another sickle type: raw material and technical pressures. In general, parallel and oblique-simple inserted blades are wider than the oblique-multiple (Figure 13A) (Mazzucco *et al.* 2018a; 2018b; 2020); thus, to replicate these traits, one needs to be able to make blades wider enough, but this width can be larger than required to wear curved sickle types. In this sense, parallel in Xúquer are only significantly different from inserted blades in the Interior area (Figure 6), and inserted blades in the South are as wide as parallel inserted in Xúquer (Figure 8), at least when Benàmer III is excluded. Thus, despite the difference detected between the blade assemblage of Xúquer and South (Figure 11), considering that the glossy blade measure achieved in the South is as wide as those used to serve as a cutting edge through parallel insertion in the Xúquer area (Figure 8), we could say that raw materials and blade technology available in both areas seem enough to develop this harvesting tool. Thus, the fact that the South continues to use the oblique-multiple type as the only harvesting tool even when the agricultural system changed poses further questions about the scales of social connectivity, which can be addressed in future work. This includes exploring the maintenance or replacement of a lithic type due to transmission constraints, more than the traditional assumption of the function as the driver of changes in lithic assemblages.

Finally, an additional scenario can explain the particularity in the harvesting and crop features of the MNA in Dehesilla cave: the presence of a new population (García-Rivero *et al.* 2019; 2020). The particularity of its record (García-Rivero *et al*. 2019), not only vegetal but also related to the domestic fauna and the ceramic assemblage (García-Rivero *et al.* 2018; 2022), makes it an exceptional cultural event. In this case, using the same sickle type with oblique-multiple inserted blades as previous groups could be explained as a common ancient trait. Once one knows the alternative functional benefits proved in experimental works (Astruc *et al*. 2012), another possibility to use this kind of sickle could be to use it as an adaption to the crop management they harvested; however, it becomes difficult to accept because experiments have confirmed every sickle's functional or practical benefits. Therefore, there is no reason to expect that a population can growth more due to using one or another type of sickle.

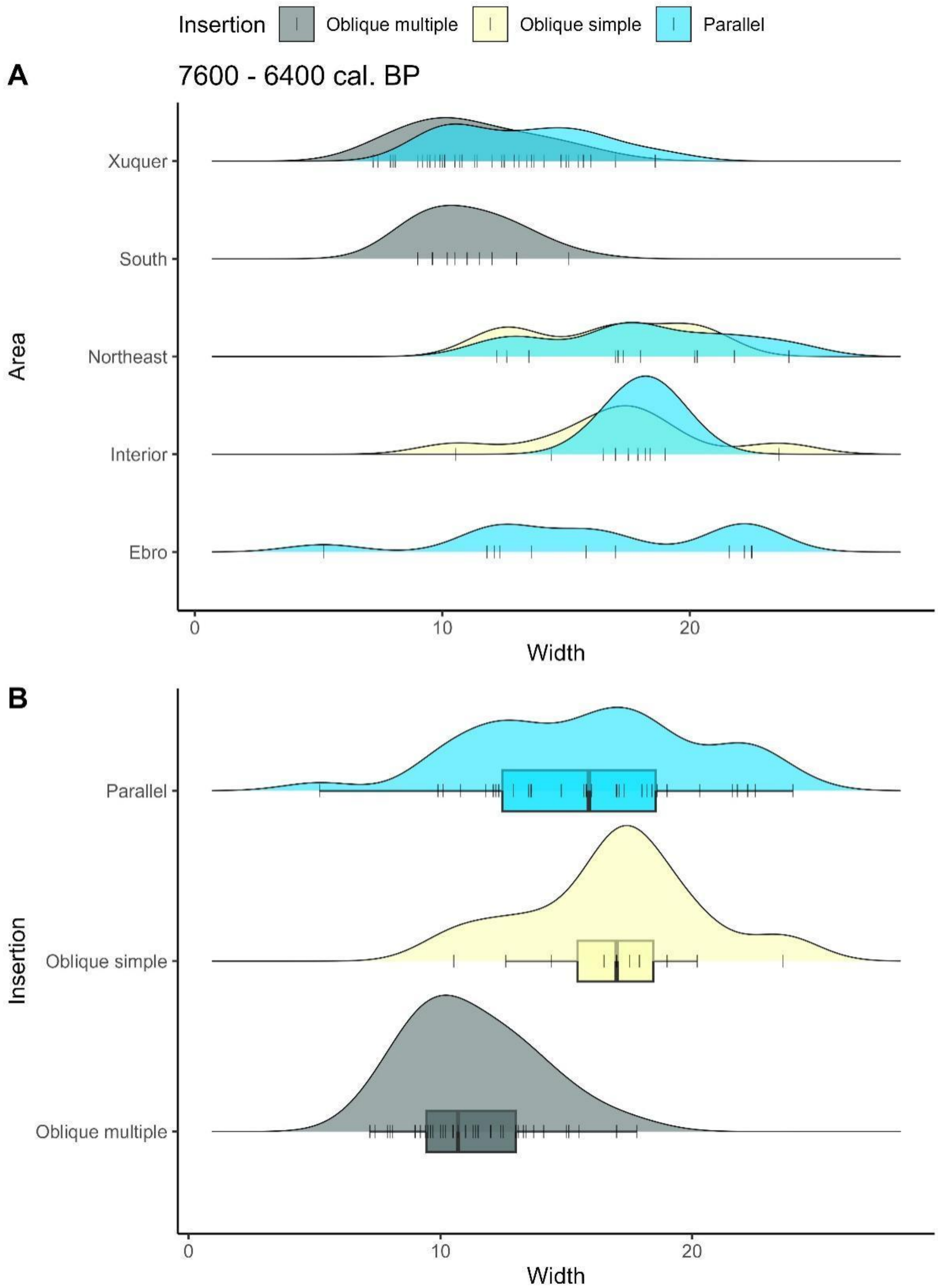

Figure 13. Boxplots from blades' width are ordered by A) Area and B) Insertion type.
Figura 13. Diagramas de caja a partir de la medida ancho máximo laminar agrupados según A) Área y B) Tipos de inserción.

4.3. Hafting constraints and blade technology

Regarding the way this technology is inserted in blade production or *vice versa*, we talked before about the apparent preference for wider blades to shape the edge in single-element edge sickle types. However, this work also observed that not all the parallel-inserted blades are broader than the oblique-multiple blades. In fact, by analysing the variation within glossy blade width, we confirm a more significant variance in parallel assemblage regarding the oblique-

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multiple type (Figure 11B), produced by selecting both narrow and wider blades to be inserted into straight shafts.

In turn, the narrowest variance in oblique-multiple types can be explained because in cases when numerous stone inserts are used in series to create an edge, blades have to fit (1) in the same slot but also (2) blades need to fit with each other to create an edge with the appropriate contours (Kuhn & Shimelmitz 2022). Thus, groups that use the multiple-insertion sickle type should be able to perform standardised blade assemblies. Differences detected between blade production measures in Xúquer and South (Figure 11) could reflect the use of different technological solutions, including, in most cases, the use of pressure or indirect percussion in the Xúquer (García-Puchol 2005: 279; García-Puchol *et al.* 2011), and the predominance of force with preliminary heat treatment in the South (Carvalho *et al.* 2012; Martínez-Sánchez & Vera-Rodríguez 2017: 70; Perales Barrón *et al.* 2015). This is undoubtedly an exciting topic that we hope to investigate further.

4.4. Diversity, transmission factors, and techno-functional constraints. A rethinking

In this work, we have tried to incorporate archaeological remains of different natures in the same interpretation over an extensive spatial and chronological framework. By filtering the sample according to a chronostratigraphic criterion and comparing changes in this cultural trait with a shift in subsistence patterns, we pursued a better understanding of cultural diversity led by neolithic groups.

Despite the trend of using one type of sickle depending on the area or the chronological phase, and according to the current data, using different types of sickle seems independent of the crop harvested. While inserting wider blades into parallel sickle types could be an adaptative trait in dealing with larger fields, additional experimental studies have demonstrated how curve and serrated sickle type can benefit harvesting activities. Thus, groups in the South did not find a limitation in using oblique-multiple sickle types to develop an extensive agricultural system. It is possible that, at that point, every harvesting artefact was functionally enough to deal with changes in crop management. This fact reinforces that crop management or agricultural systems were not decisive constraints in reproducing the “inserted type” trait in the harvesting toolkit over the Iberian Peninsula’s Early and Middle Neolithic, so probably in this framework, cultural changes reflect the groups' replacement.

Regarding the technological factor, shafting could constrain the blade selection or production, especially in the multiple-inserted version. According to blade analysis, human population in Xúquer and South performed technical solutions to get a blade assemblage standardised enough to respond to this constraint, even if they performed different productions.

We are fully aware that if we want to confirm some of these hypotheses, we need to increase the sample over time, especially in the last phases and throughout space, and include other kinds of cultural traits in the discussion. In the meantime, and despite the sample size limitation, comparing changes in potentially related remains seems to be a good practice to discard factors of change within the material culture, thus improving the understanding of changes in the behaviour of the neolithic communities over time and space.

However, despite the efforts and diligence applied to filter the included contexts, achieving the desired chronological resolution for analysing changes has proven challenging. Among the difficulties encountered in this endeavour, it is noteworthy to highlight the frequent absence of contextual detailed publications about archaeological artefacts. While there are growing efforts to reconstruct the events of occupation at archaeological sites, a more comprehensive understanding of population evolution needs a heightened commitment from researchers to share high-quality data beyond the radiocarbon data.

Data accessibility

Supporting data are available in the supplementary material.

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Evolución en la Tecnología de Cosecha: Un Estudio de Diversidad a partir de Restos Líticos y Botánicos en el Neolítico Ibérico (8th-7th milenio cal. BP)

María Barrera-Cruz [1], Oreto García-Puchol [1], Alfredo Cortell-Nicolau [2], Daniel García-Rivero [3]

1. Grupo de Investigación PREMEDOC, Departamento de Prehistoria, Arqueología e Historia Antigua, Universidad de Valencia. Av. Blasco Ibañez 28, 46010 València, España. Email: MBC: maria.barrera@uv.es; OGP: oreto.garcia@uv.es
2. University of Cambridge. McDonald Institute for Archaeological Research, Department of Archaeology, University of Cambridge, Downing Street, CB2 3DZ, Cambridge, UK. Email: ac2320@cam.ac.uk
3. Departamento de Prehistoria y Arqueología, Universidad de Sevilla. Doña María de Padilla, s/n, 41004, Sevilla, España. Email: garciarivero@us.es

Resumen:

Hacia la primera mirad del 8th milenio cal. BP llegaron a la península Ibérica los primeros grupos de agricultores. Desde entonces, continuó la expansión de nuevas poblaciones, y la diversidad de la cultura material que nos proporcionan los contextos neolíticos se ha interpretado como un reflejo tanto de los múltiples orígenes de estos grupos como de la regionalización que siguió a su llegada. En las últimas décadas, el estudio de diferentes herramientas líticas ha servido para explorar patrones culturales del periodo. En particular, la detección de cambios en la tecnología de recolección ha proporcionado información útil sobre el origen y difusión de los grupos neolíticos, proponiéndose como posibles factores explicativos de los cambios posteriores transferencias en la tecnología o incluso la adaptación cultural a cambios agrícolas. Este trabajo busca comparar continuidades y discontinuidades entre los factores económicos, sociales y técnicos caracterizando el cultivo cereal, la producción de láminas y los elementos de hoz según distintas áreas entre el 7600 y el 6400 cal. BP en una escala cronocultural amplia. Como resultado, se confirma que el uso de un tipo de hoz es independiente del cultivo cosechado y, al menos hasta el Neolítico Medio, observamos que no limita la incorporación del nuevo sistema agrícola en la región. Al incluir en el análisis las medidas de láminas con pátina y de producciones laminares, descartamos limitaciones tecnológicas en aquellas áreas donde no se introdujo el uso del tipo de inserción paralela. Además, encontramos diferencias significativas entre los coeficientes de variación de las láminas insertas de diferentes maneras, probablemente relacionadas con restricciones de enmangue y, cuando los datos lo permitieron, discutimos la forma en que la producción laminar se adaptó a ellas. La incorporación de filtros en el proceso de selección de la muestra a favor de conjuntos datados permitió situar estos patrones en una escala comparativa de doscientos años.

Palabras clave: Neolítico, Península Ibérica, Tecnología de cosecha, Restricciones de enmangue, Ecología