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Harvesting tools and the spread of the Neolithic into the Central-Western Mediterranean area

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ABSTRACT

This paper discusses the current state of research on harvesting technologies of the first farming communities of the central and western Mediterranean area between *ca.* 6000–5900 cal BC and 4800–4700 cal BC. New data obtained from the analysis of almost 40 sites from the Italian Peninsula is compared with data previously collected from the Iberian Peninsula and southern France. Results indicate the existence of at least two different harvesting traditions, one characterized by curved sickles used for harvesting at a low or middle height; the other characterized by reaping knives with parallel hafted blades, probably mainly used for ear harvesting. Processes of innovation and change have been highlighted, suggesting that harvesting techniques changed and evolved through time. Besides, the mechanism and pace of diffusion of curved sickles have been explored, too.

1. Introduction

Harvesting tools are an important source of information on agricultural systems. From prehistory to modern and contemporary times, the choice of an appropriate crop harvesting technique has always represented a fundamental aspect of agrarian production. The adoption of sickles, scythes or other hand or mechanical harvesting methods, largely responds to both technical and economic determinants. For example, harvesting techniques are often adapted to the type of cultivated plants and sought products (e.g. whole plants, whole ears only, individual grains, leaves only, etc.) (Anderson and Sigaut, 2014); at the same time, especially during the last century, most of the crops have been genetically modified to make them more suitable for the mechanized harvesting systems available (Donald, 1968).

Harvesting itself probably played a role in the domestication process, bringing about an unconscious selection of plants, favouring non-shattering specimens over shattering morphotypes (Hillman and Davies, 1990; Anderson, 1999; Fuller et al., 2010). On the basis of recent data, it seems that stone tools were used for harvesting since the earliest trials of cultivation, almost ten thousand years before the appearance of the so-called Neolithic revolution (Snir et al., 2015). During the twelfth millennium BC, Natufian groups used sickle blades for harvesting green cereals; during Late Natufian and PPNA periods, harvesting tools were used to collect (semi-cultivated) semi-ripe cereals, while the Middle/Late PPNB would corresponds to the period when morphologically domestic crops began to be more abundantly harvested (Ibáñez et al., 2016). Through all of these periods, harvesting tools underwent several changes from both a technological, in terms of the flaking system related to the production of the stone inserts, and a morphological point of view, in terms of the overall shape and morphology of the harvesting tool (Rosen, 1997; Anderson, 1999; Ibáñez et al., 2007; Shirai, 2016; Maeda et al., 2016).

As agriculture began to spread into the Mediterranean basin around the end of the eighth millennium BC, Neolithic groups brought domesticated crops to new regions together with a complex set of technologies and knowledge necessary to cultivate, harvest, store, process and consume them. Harvesting tools were definitely one part of this package. Unfortunately, in most of the archaeological contexts perishable materials are not preserved and stone inserts are all that remains of those instruments. Those stone

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tools, made of chert and, to a lesser extent, obsidian, are usually called 'glossy' or 'sickle' blades by archaeologists, because of their characteristic sheen. This sheen or lustre is the result of a both additive and abrasive wear process caused by the contact between the stone edge and the reaped plant while harvesting (Anderson, 1999).

Over the last ten years, an international team of use-wear specialists has started a research project focusing on the first evidence of agriculture in the Iberian Peninsula and South-East France during the Neolithic Age. As a result, it has been demonstrated that the harvesting technologies, largely adopted by the first European farmers, were not homogeneous, since a variety of different tools and techniques existed (Ibáñez et al., 2008; Gassin et al., 2010; Gibaja et al., 2016; Pichon, 2017).

In more recent papers (Mazzucco et al., 2016; Ibáñez et al., 2017), we have been trying to relate the variability observed amongst the Neolithic harvesting traditions to different routes of expansion followed by the colonizing groups, suggesting the existence of at least three waves of expansion across Europe: the *Linearbandkeramik* route towards central and northern Europe, a maritime route along the Tyrrhenian coasts and a land route along the northern Mediterranean basin.

However, our previous point of view on harvesting technologies amongst Early Neolithic communities in the central-western Mediterranean area was limited by the scanty direct data from Italian sites. In order to strengthen our hypothesis about the expansion of Neolithic groups in the central-western Mediterranean regions, and taking into account 34 of the most important lithic collections of the Italian Early Neolithic Age, this paper aims to provide a detailed and direct evidence of the type of harvesting tools used by the first migrants that settled in the Italian Peninsula during the sixth and the first quarter of the fifth millennium cal BC, more specifically between 6000 and 5900 cal BC and 4800–4700 cal BC. The analysis of lithic inserts, their technological characteristics and the use-wear marks found on the edges will give information on their methods of hafting, use and management. The hypothesis of a dichotomy (Mazzucco et al., 2016), in terms of harvesting tradition adopted, between the peninsular and the alpine-continental regions of Italy will be explored. Moreover, in order to test a wave-of-advance model of the spread of harvesting technologies throughout the Mediterranean area, a kriging interpolation will be applied to a sample of the collected data.

2. Background of the study: the western Mediterranean area

Starting from the inverse perspective, from west towards east, the Neolithic arrived on the westernmost European coasts between *ca*. 5600 and 5500 cal BC. Sites such as Vale Pincel I (Alentejo), Cabranosa and Padrão (Algarve), bear evidence of the beginning of farming practices in such an early phase. Despite that, the Neolithization of Portugal is still a moot question in several respects. The local radiocarbon framework is still deficient in dates from domesticated species and the poor preservation of the bioarchaeological remains does not allow for a detailed description of the locally adopted farming system. Moreover, while clear similarities exist between Andalusian and Portuguese Neolithic contexts, the role of a possible North African wave of expansion is more difficult to assess. Probably a recomposition of the Neolithic package took place, with some elements that were modified and some new ones that were introduced through contacts and exchanges between the two shores of the Strait of Gibraltar (Manen et al., 2007; Cortés Sánchez et al., 2012; Linstädter et al., 2012, 2016). However, on the basis of current data, a North African route of expansion for harvesting technologies seems unlikely, as until this moment no glossy blades have been recognized in this region (Gibaja et al., 2012). Moreover, in several Neolithic sites of North Africa cereals covered a minor role in the economy, while wild plants appear more intensively exploited (Lucarini et al., 2016; Morales et al., 2016).

Vale Pincel I is the site that has provided more data about the early harvesting techniques in Portugal (Soares et al., 2016), even if a few sickle blades have also been recovered from the sites of Cortiçóis (Carvalho et al., 2013). All of them witness the employment of a curved sickle with diagonally-inserted stone cutting edges; lithic artefacts, often intentionally broken to produce a sharp ninety-degree corner, range from 1.6 to 4 cm in length, from 0.7 to 1.3 cm in width and from 0.2 to 0.4 cm in thickness, and always consist of tools made on blade or bladelet blanks, occasionally shaped by abrupt retouch at one or both ends in order to facilitate its insertion into the haft.

Technical traditions observed in Portugal were largely shared amongst Andalusian Neolithic groups, not only for what concerns harvesting techniques, but also about other technical know-how (i.e. heat treatment, abruptly-retouched segments and pottery decoration motifs) (Manen et al., 2007; García-Borja et al., 2014). Also southern Spanish lithic production relies on small blades and bladelets —on average 0.6–1.3 cm wide, 0.2–0.4 cm thick–, which often bear signs of heat treatment and were flaked by the pressure technique (Carvalho et al., 2012; Perales et al., 2015). To produce sickle inserts, blades were intentionally broken and little time was spent for retouching tools. At Los Murciélagos de Albuñol Cave, near Granada, a complete sickle of this type was found in the mid-nineteenth century (Góngora, 1868: 199); although the original tool has been lost, some old drawings seem to confirm that it was similar to the ones recovered at La Marmotta in Central Italy (Fugazzola Delpino et al., 1993) (Fig. 1).

The use of this type of sickle characterized the entire southern coast of the Iberian Peninsula, from the Spanish Levant to the Portuguese coasts, including some early 'pioneering' occupation (*ca*. 5600–5500 cal BC) in Catalonia and southern France, such as at Les Guixeres de Vilobí (Barcelona, Early Cardial) (Ibáñez et al., 2017), and Peiro Signado (Languedoc, Impressed-Ware period) (Philibert et al., 2014). The characteristics of the sickle blades are the same as previously stated. A few larger blades, up to 6–8 cm in length, have been detected at Cova de l'Or and Cova Sarsa; however, they show a diagonally-distributed gloss as well. They might belong to curved sickle of larger dimensions, or might be part of the same sickle together with the smaller bladelets; this confirms that even when larger blanks were available the hafting method did not change (Gibaja et al., 2010).

Carpological data for Levantine and southern Spain indicates a prevalence of free-threshing cereals (*Triticum aestivum-durum* and, to a lesser extent, *Hordeum vulgare* var. *nudum*), although hulled wheat (*Triticum monococcum-dicoccum*) is also represented, especially in early Valencian sites (Pérez-Jordà, 2005). Some remains of low-growing cereal weeds such as *Asperula arvensis* and *Valerianella dentata* suggest that at least in some sites plants were cut at low heights, thus collecting a large part of the stralk (Pérez-Jordà et al., 2011).

Moving north into Catalonia and southern France, harvesting technology radically changes, with the appearance of L-shaped wooden sickles. This harvesting tradition quickly penetrated (*ca*. 5400–5300 cal BC) the inner areas of the Iberian Peninsula, while on the Atlantic façade late hunter-gatherer populations probably adopted an alternative method, namely ear plucking or plant uprooting (Ibáñez et al., 2001, 2008).

Several wooden L-shaped sickles have been recovered from the waterlogged site of La Draga (Palomo et al., 2011) (Fig. 1); they show two different variants: the first with a fairly long blade (5–9 cm in length), inserted parallel to the wooden handle, whilst, in the

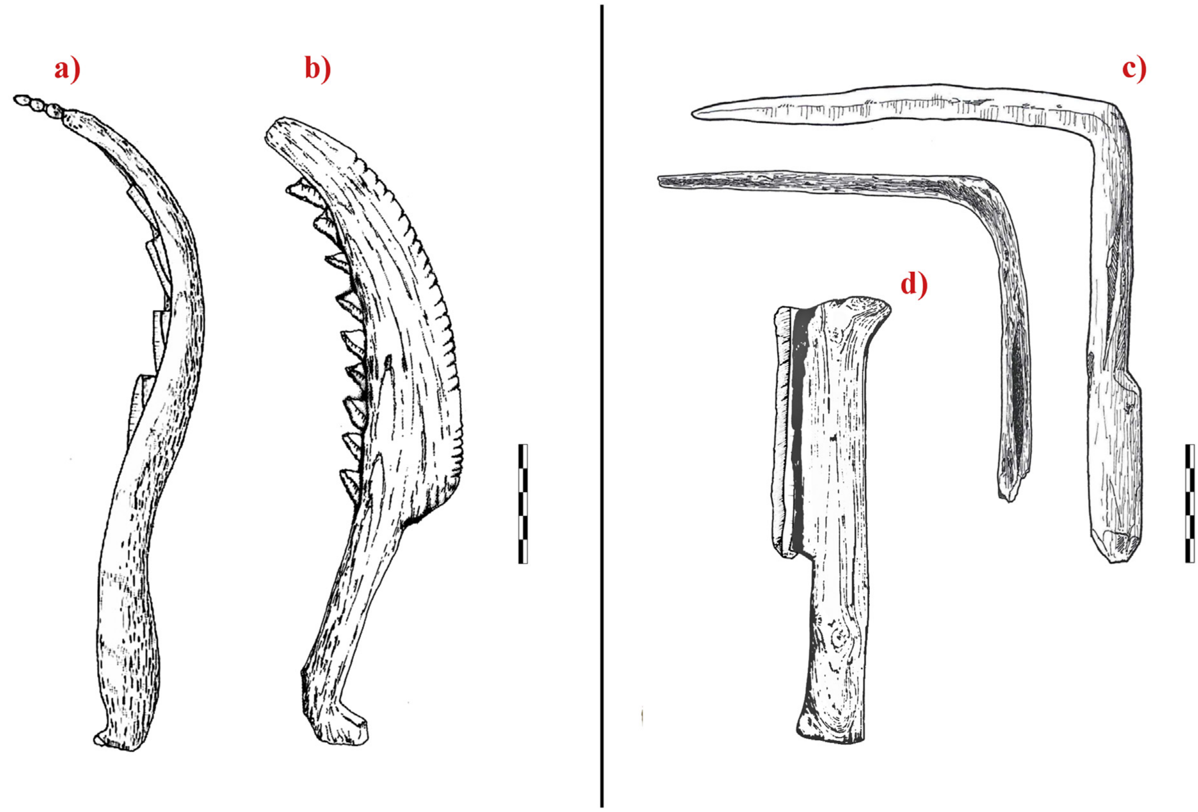

Fig. 1. Some examples of complete harvesting tools. A-B – curved sickles: a) Antler sickle from Karanovo (modified after Gurova, 2014); b) Wooden sickle from La Marmotta (modified after Pessina and Tiné, 2008). C-D – straight reaping knives – c) Wooden sickle from La Draga (modified after Bosch et al., 2006); d) Reaping knife from Auvernier-Port (modified after Egloff, 1984).

second one, the blade of same size was inserted obliquely into the shaft of the sickle. Experimental tests have proved that both variants were used following a two-step movement: the first to gather the stems and the second, after turning the tool by moving the wrist, to cut them. This movement fits well with a cutting at a middle height aimed at harvesting plant's ears only, instead of the whole stalk; cutting at ground level is unfeasible indeed. Moreover, such a harvesting movement is not really viable in densely-sown fields as, while rotating the wrist, it is easy to damage the near plants with the tool.

Archaeobotanical data from La Draga suggests about naked wheats –the main crops at the site– that the (whole) ears were harvested, specifically by a high-standard technique. Actually, the only crop weeds recovered there are climbing taxa (*Papilionaceae*), which were collected even by cutting them at a high point, whereas low weedy plants are absent (Antolín et al., 2014). Crops were later probably threshed using a blade, thus leaving the characteristic abrasive traces (Clemente and Gibaja, 1998).

Blades with a parallel distributed gloss are common to most of the Cardial and Chasseen sites of southern France (Gassin et al., 2010). Crop is there represented by free-threshing cereals (naked wheats and barley), as is the case with Catalonia, but also southern Spain, this suggesting that no direct relation exists between the type of harvesting tools and that of cultivated species.

3. Materials and methods

This study is based on the technological and traceological analysis of the glossy blades from 34 Early Neolithic sites or settlement phases in the Italian Peninsula (Fig. 2; Table 1). The method and the approach followed for the analysis have already been subject of several publications (González Urquijo and Ibáñez, 1994; Marreiros et al., 2015; Mazzucco and Gibaja, 2016). Lithic collections have been examined in their entirety to point out their technological features according to the criteria as in Inizan et al. (1999) and Pelegrin (2012). After a first assessment of the assemblage, only blade blanks have been selected for a more detailed traceological analysis. Glossy blades are often easily recognizable with the naked eye; nevertheless, all blades have been submitted to macroscopic observation through a stereoscopic microscope, in order to detect even very marginal traces. Selected tools have successively been analysed through a reflected-light microscope (N300 Nikon Labophot and Olympus BH2), in order to highlight the micro textural characteristic of the polish. As a result, a total of 585 glossy blades have been detected.

In addition, in order to create a diffusion model of harvesting technologies across the central and western Mediterranean regions, a well-known geostatistical method has been employed, called kriging and based on the spatio-temporal analysis of radiocarbon-dated archaeological contexts. Kriging is based on the idea that the value at an unknown point should be the average of the known values at its neighbours; weighted by the neighbours' distance from the unknown point (Cressie, 1993; Stein, 1999; Montero et al., 2015). The existence of a spread in our data can be ascertained by detecting a space-time gradient, which depends on a similarity in neighbouring regions (Tobler, 1970), spatial gradient and directivity.

A wave-of-advance model has been tested by our data; this model has been used to describe different spread phenomena, such as demic diffusion, cultural transmission and adoption of innovations (amongst others Ammerman and Cavalli-Sforza, 1971; Pinhasi et al., 2005; Bocquet-Appel et al., 2009; Barceló et al., 2014;

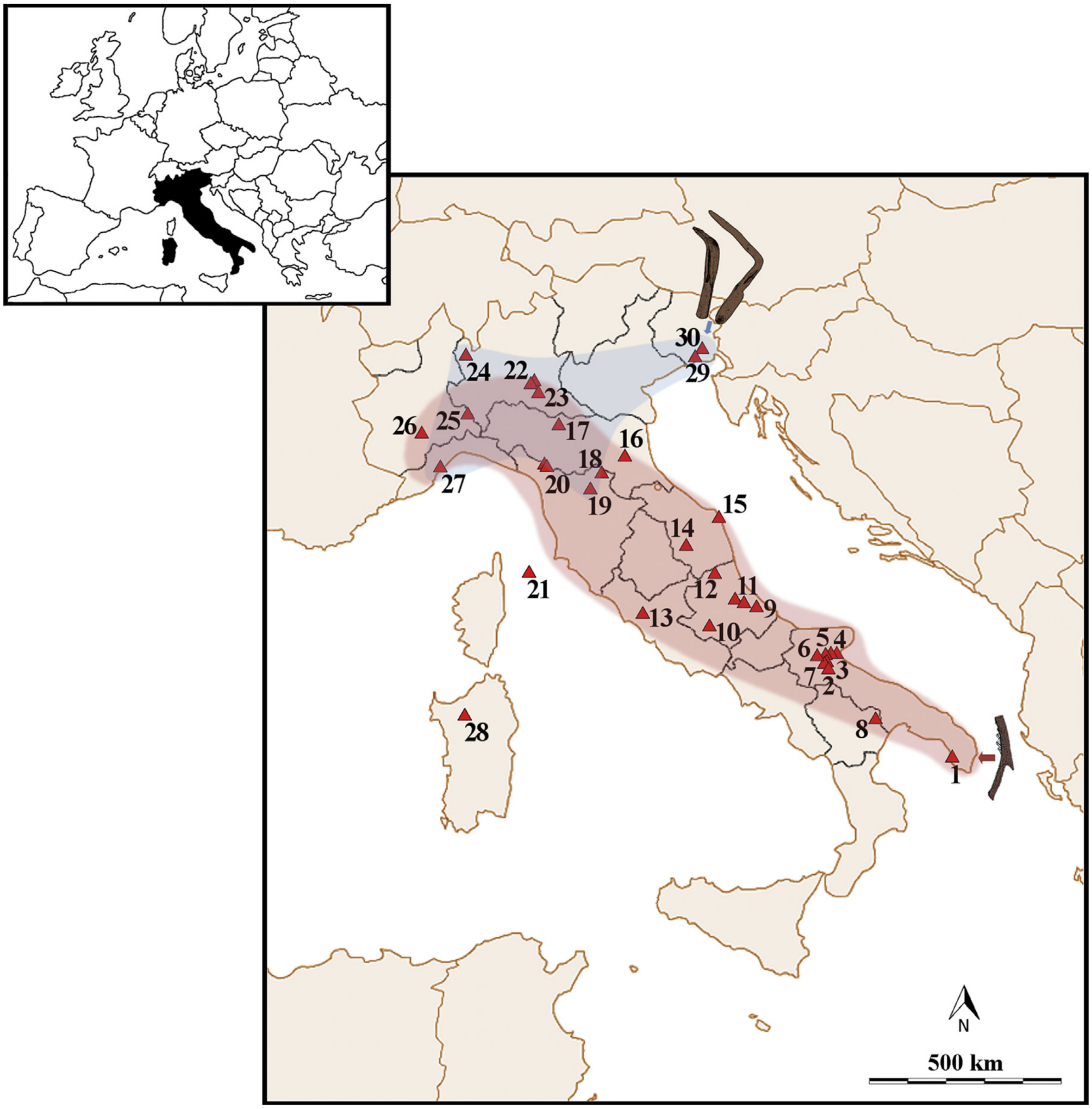

Fig. 2. Geographical framework. Red triangles are the archaeological sites cited in the text and tables. APULIA: 1) Torre Sabea; 2) Ripa Tetta; 3) Coppa Nevigata; 4) Masseria Candelaro; 5) Passo di Corvo; 6) Masseria Acquasalsa; 7) Ex-Palestra GIL and Masseria Pantano; BASILICATA: 8) Trasano; ABRUZZO: 9) Marcianese; 10) Colle Santo Stefano; 11) Catignano and Colle Cera; 12) Grotta Sant'Angelo; LAZIO: 13) La Marmotta; MARCHE: 14) Maddalena di Muccia; 15) Portonovo; EMILIA-ROMAGNA: 16) Fornace Cappuccini; 17) Rivaltella; TUSCANY:18) Cialdino; 19) Mileto; 20) Muraccio and Pian di Cerreto; 21) Cala Giovanna; LOMBARDY: 22) Campo Ceresole and Ostiano Dugali; 23) Isorella; 24) Pizzo di Bodio; PIEDMONT: 25) Brignano Frascata; 26) Alba; LIGURIA: 27) Arene Candide; SARDINIA: 28) Su Coloru; FRIULI: 29) Piancada; 30) Sammardenchia. The red zone indicates the area of diffusion of curved sickles. The blue zone indicates the area of diffusion of the straight reaping knives. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Brami and Zanotti, 2015). Specifically, for describing the adoption of reaping tools, an Empirical Bayesian Kriging (EBK) algorithm has been employed, in order to identify a variation in space, defined by geographic coordinates x, y, and in time, measured by medians of calibrated ^{14}C dates. The advantage offered by EBK is that it automatically calculates the parameters of the kriging model and yields more accurate outcomes, in particular about small datasets. We have chosen a Whittle semivariogram model, which assumes that the similarity between data slowly diminishes over distance.

The geostatistical analysis has been carried out using ArcGIS 10.3 software, by focusing on the diffusion of curved sickles in the central and western Mediterranean area. Only the first occurrences of diagonally-hafted blades on a regional scale have been retained for this study. We have excluded from the analysis the other reaping tools, because the available data is still insufficient to calculate a model; more sites are needed to trace the diffusion of La Draga-type reaping knives across the Mediterranean basin.

A total of 20 radiocarbon-dated archaeological contexts associated with diagonally-hafted blades from the central-western Mediterranean regions have been selected. For each region, the priority has been given to ^{14}C dated samples coming from short-lived remains (when available); dates from disturbed contexts, like pits cutting underlying Mesolithic layers, or dates with standard deviations over 100 yrs have been excluded when alternative

Table 1
Analysed sites and number of recognized glossy blades.

Region	Site	Chronology	Culture	Lithic assemblage	Analysed sample (blades)	N° glossy blades	Composite bended sickles: glossy blades	Straight reaping knives: glossy blades	Indet. Hafting
Apulia	Ex-Palestra GIL	mid of the 6th mill.	Passo di Corvo	150	52	9	7	–	2
Apulia	Masseria Acquasalsa	mid of the 6th mill.	Masseria La Quercia/ Passo di Corvo	114	47	3	2	–	1
Apulia	Masseria Candelaro-lay4	1st half of the 6th mill.	Masseria La Quercia	1706	226	8	7	–	1
Apulia	Masseria Candelaro-lay3	1st half/mid of the 6th mill.	Passo di Corvo	1426	246	7	4	1	2
Apulia	Masseria Candelaro-lay2	mid/2nd half of the 6th mill.	Diana	1589	156	10	9	–	1
Apulia	Masseria Pantano	mid of the 6th mill.	Masseria La Quercia/ Passo di Corvo	75	17	7	5	–	2
Apulia	Passo di Corvo	mid of the 6th mill.	Passo di Corvo	554	156	34	33	1	–
Apulia	Ripa Tetta	beginnings of the 6th mill.	Impressa/Guadone	8268	330	61	57	–	4
Apulia	Torre Sabea	end of the 7th/beginnings of the 6th mill.	Impressa	472	107	17	17	–	–
Basilicata	Trasano-I	end of the 7th/beginnings of the 6th mill.	Impressa	n/a	123	10	6	2	2
Basilicata	Transano-II	beginnings of the 6th mill.	Impressa evoluta	n/a	46	4	–	–	4
Basilicata	Transano-III	1st half/mid of the 6th mill.	Impressa evoluta	n/a	172	24	16	1	7
Abruzzo	Catignano	mid of the 6th mill./5th mill.	Catignano	5836	1362	24	21	–	3
Abruzzo	Colle Cera	end of the 6th mill.	Catignano	1119	515	23	19	1	3
Abruzzo	Colle Santo Stefano	6th mill.	Impressa	4596	252	144	119	–	25
Emilia-Romagna	Rivaltella	end of the 6th/beginnings of the 5th mill.	VBQ	678	432	10	–	4	6
Emilia-Romagna	Fornace Cappucini	2nd half of the 6th mill.	Impressa	7608	3595	38	33	–	5
Tuscany	Cala Giovanna	6th/5th mill.	Linee Incise	4764	150	3	–	2	1
Tuscany	Cialdino	mid/2nd half of the 6th mill.	Linee Incise/ Impressa	n/a	88	1	1	–	–
Tuscany	Mileto	end of the 6th	Linee Incise/ Fiorano	129	41	1	–	1	–
Tuscany	Muraccio	end of the 6th	Linee Incise/ Fiorano	740	486	0	–	–	–
Tuscany	Pian di Cerreto	6th mill.	Linee Incise/ Fiorano	1317	672	0	–	–	–
Lombardy	Campo Ceresole	beginnings of the 5th mill.	Vhò	2156	802	18	17	–	1
Lombardy	Isorella	end of the 6th/beginnings of the 5th mill.	Vhò	≈700	211	5	–	3	2
Lombardy	Ostiano Dugali	end of the 6th/beginnings of the 5th mill.	Vhò	4264	429	21	18	–	3
Lombardy	Pizzo di Bodio-phase1	beginnings of the 5th mill.	Isolino	547	221	1	–	1	–
Lombardy	Pizzo di Bodio-phase2	1st half of the 5th mill.	VBQ	734	81	1	–	1	–
Piedmont	Alba	beginnings of the 5th mill.	Vhò	390	127	2	1	–	1
Piedmont	Brignano Frascata	end of the 6th/beginnings of the 5th mill.	Vhò	1092	269	10	3	3	4
Liguria	Arene Candide-Impressa lay25-24/ 15-14	1st half of the 6th mill.	Impressa	510	152	4	1	–	3
Liguria	Arene Candide-VBQ lay22-16/12	beginnings of the 5th mill.	VBQ	818	217	19	1	9	9
Sardinia	Su Coloru	1st half of the 6th mill.	Impressa	229	21	1	1	–	–
Friuli	Piancada	2nd half of the 6th mill.	Gruppi Friulani	≈1700	503	28	–	16	12
Friuli	Sammardenchia	6th/5th mill.	Gruppi Friulani	≈50,000	1337	37	–	30	7

dates existed. However, given the general poor quality of the radiocarbon record –especially for southern Italy, where only old non-AMS dates are available–, we had to retain several dates characterized by large standard deviations (i.e. ±130, ±140, ±150, ±160 yrs, etc.).

4. Results: harvesting technologies in the Italian Peninsula

4.1. South Italy

South Italy is considered one of the key areas for the understanding of Neolithic Europe and the spread of this culture across the Mediterranean basin. The 'ditched villages' discovered through aerial photography by Bradford (1949) are one of the symbols attesting the coming of farming groups to the Italian shores; new open-air settlements were later discovered during the eighties and nineties in both northern and southern Apulia (Cremonesi et al., 1987; Conati Barbaro, 2004).

Lithic production in Apulia is characterized by the exploitation of chert sources from the Gargano promontory (Tarantini et al., 2016); Gargano chert shows technical characteristics that clearly differentiate it from that of the Apennines, namely, local cherts which generally consist of pebbles of smaller size and reduced knappability. Cherts were exploited for the production of blades that were on average 1.3–1.7 cm wide, probably using standing pressure as main reduction technique; indirect percussion is also occasionally attested, mostly when raw materials different from the Gargano types were used (Guilbeau, 2011).

In this context, diagonally-hafted sickle inserts have been documented in all of the analysed collections as one of the most recurrent tool types since the earliest Neolithic phases of South Italy (*ca*. 5990−5660 cal BC) (Table 1); they were made of both Apennine and Gargano cherts, by breaking the blade distally or proximally and occasionally retouching it laterally to form an abrupt edge (Fig. 3). Sickle inserts of this type are also known from Coppa Nevigata's Impressed-Ware layers (Ronchitelli, 1987) and Ripa Tetta (Giampietri and Tozzi, 1989), even if in the latter site inserts show a greater variability of shapes and methods of hafting (Petrinelli Pannocchia, 2014).

Gargano chert was also used to produce wider and longer blades −up to 2.3−2.2 cm wide and 18−22 cm long− using the lever pressure technique (Pelegrin, 2012). Although they are often broken, long pressure blades appear in several industries of the regions of Apulia and Basilicata during the Impressa-Ware and the Painted-Ware phases (e.g. Torre Sabea, Trasano, Masseria Candelaro, Masseria Acquasalsa, Masseria Pantano, Passo di Corvo) (Tiné, 1970; Guilaine and Cremonesi, 2003; Lemorini et al., 2004; Muntoni et al., 2012; Mazzucco et al., 2013; Muntoni and Scopece, 2014; Muntoni et al., 2016). Those blades were probably produced by a few knappers for supplying several communities. Therefore, they should be considered as a specialized production, quite distinctive with respect to the rest of the flaked stone industry (Guilbeau, 2012).

During the Impressa period long blade production still appears to have been to a limited extent and it is possible that some Neolithic communities were not provided with such blades. A gradual increase possibly took place as from the Painted-Ware phases as documented by the evolution in the frequency of Gargano blades from the earliest to the more recent phases of Masseria Candelaro (from *ca*. 5640−4590 to 5300−5040 cal BC) (Conati Barbaro, 2004). This also fits with Passo di Corvo's lithic assemblage, dated to the phase of the same name (*ca*. 5290−4930 cal BC), where the industry is composed almost exclusively of Gargano chert, with several fragments of lever pressure blades (Guilbeau, 2010).

A remarkable aspect is that, despite showing long and regular cutting edges, Gargano lever pressure blades were rarely employed as harvesting tool. Several of them were used for butchering, cutting and scraping animal hides or graving bone/antler, and they often show an overlap of different activities on the same edge, thus suggesting a long-term use of the tool (Lemorini et al., 2004). Some of the blades were also used for cutting vegetal substances, such like non-ligneous plants; however, they do not bear traces of an intense use (Fig. 4, a). This might indicate that long blades were employed for quick works associated with plant gathering activities, not necessarily related to agricultural production (Fig. 3, a). Interestingly, long blades showing an overlap of activities, related not only to plant gathering tasks, are also known from Franchthi Cave in Greece (Perlès and Vaughan, 1983).

Only in a few cases a well-developed, intense, glossy patina resulting from cereal harvesting has been detected on long blades made of Gargano chert; one from Trasano-I (*ca*. 5950−5720 cal BC), one from Trasano-II (*ca*. 5710−5560 cal BC), one from the Painted-Ware layer of Masseria Candelaro-structure Q/layer 3 (*ca*. 5620−5510 cal BC)- and one from Passo di Corvo-ditch F (*ca*. 5290−4930 cal BC) (Fig. 4, b). In any case, tools were later reused for other activities, this confirming the hypothesis of this type of blanks having been used for a long time. Moreover, blades appear to have been employed as knives, since they were hafted axially, bearing traces on both edges, and laterally into the haft.

Long and large blades were also occasionally broken into rectangular/quadrangular pieces and used as inserts for curved sickles (Fig. 3, c), despite the vast majority of inserts being made on narrow blanks (Fig. 3, a-b). As suggested above, this might be the result of a long-term management strategy, in which long pressure blades were initially used as knives, exploiting their entire length, and then for different purposes (i.e. butchering, hide working, plant gathering, etc.), whilst only in the later stages of their life they were split into several parts and transformed into sickle inserts. This data suggests that during the Early Neolithic period long blades were not produced to be transformed into specialized, single-purpose tools, but for a variety of tasks, depending on context and needs. They were only occasionally used in plant harvesting activities and did not substitute for the common, everyday crop harvesting tool, which was represented by a curved sickle with diagonally-hafted stone inserts.

In this context, the appearance of a few long blades employed as reaping knives in Early Neolithic South Italy can be regarded as an opportunistic behaviour, a consequence of the adoption of the lever pressure technique rather than a specific innovation about harvesting technologies. Indeed, although the production of pressure lever blades was highly specialized, these blades were used for various types of tools and this indicates that the production of sickle blades was not specialized with respect to other lithic types. On the basis of current knowledge −even if more data is needed, especially for the Middle and Late Neolithic periods−, it seems that a substitution of long crop reaping knives for curved sickles would have occurred only later, during the Late Neolithic and Chalcolithic period, when a clear intensification of the production of long blades can be observed (Guilbeau, 2015), and when those tools were more systematically employed for crop harvesting tasks, as it has been noted in other European contexts (Plisson and Beugnier, 2007; Linton, 2016).

4.2. Ligurian coasts

Liguria's coasts are regarded as an example of an early 'pioneering' colonization by Neolithic groups. Several excavation campaigns at Arene Candide revealed the existence of Impressa-Ware layers dated to *ca*. 5800−5700 cal BC; such an early occupation has been documented in other sites of the region with similar chronologies (Biagi and Starnini, 2016). At Arene Candide only four glossy blades have been recovered from the Impressa-Ware layer, considering both Bernabò Brea-Cardiníś and Tiné's excavations (Starnini, 1999; Starnini and Voytek, 1997). Tools are highly fragmentary, as a result of retouching/retooling practices. This often happens in cave contexts where glossy blades, after being used for harvesting elsewhere, were transported and transformed into new tools (Mazzucco et al., 2015). Only one sickle blade is complete: a small blade retouched laterally and hafted diagonally in a curved sickle (Fig. 5, a). After the first use, the blade was turned, retouched on the opposite side and so reused; this explicates why it was typologically classified as a borer (Starnini, 1999: 450). Later, during the VBQ-Middle Neolithic phase, around 5000−4600 cal BC, a break in the type of sickle blades can be observed at Arene Candide, with the appearance of straight glossy blades hafted in parallel fashion. Starnini and Voytek (1997) also noted that in VBQ layers blades of larger size were preferred to produce sickle inserts.

4.3. Central Italy and Sardinia

As they spread toward Central Italy, Neolithic groups would probably have followed both a maritime (Bagolini and Von Eles, 1978) and a land route across the Apennine range (Cazzella, 2000); from an earlier Impressa-Ware phase, they would rapidly have evolved different regional styles, with a strong dichotomy between the Adriatic and Tyrrhenian coasts. However, about harvesting technologies, the scenario appears quite

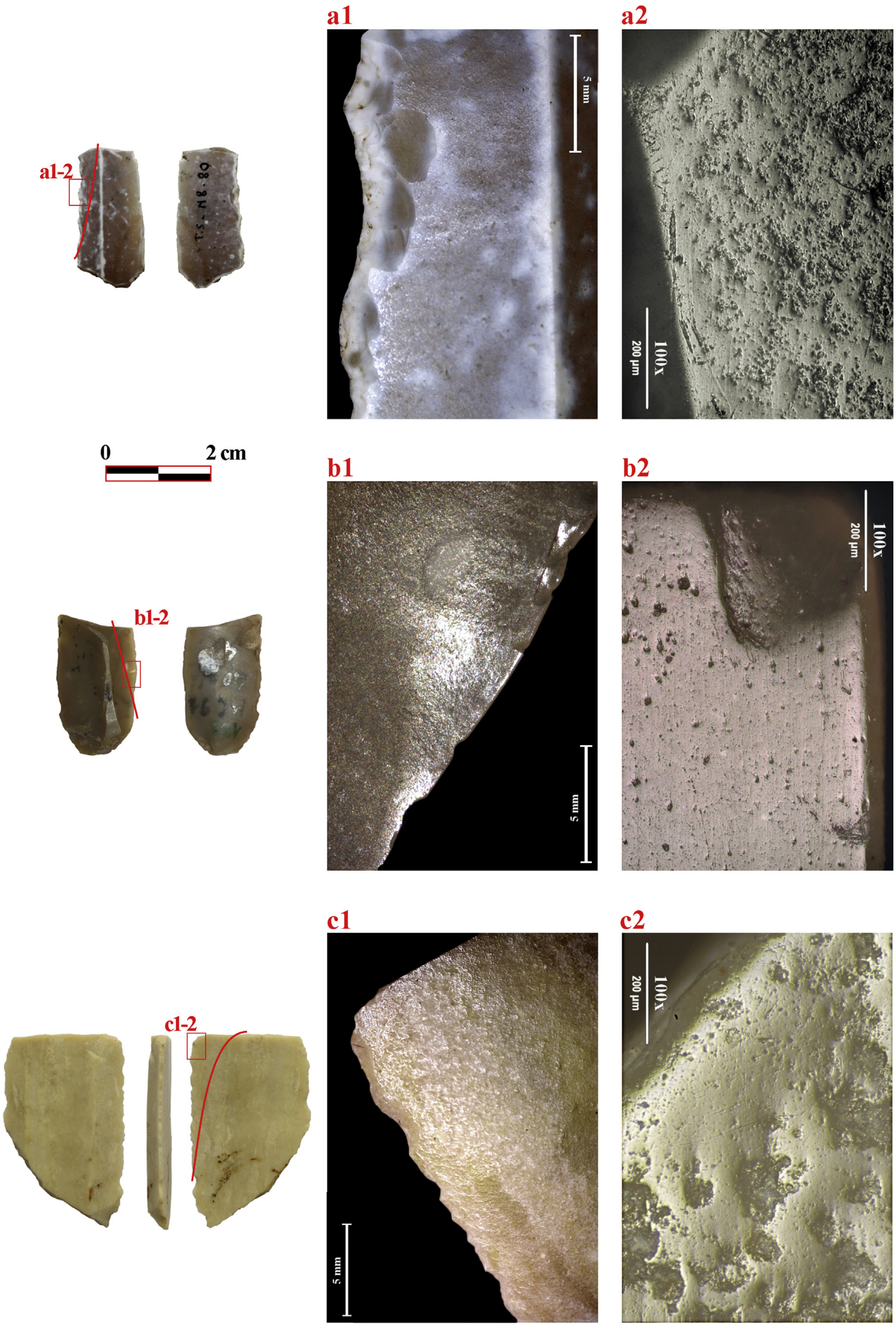

Fig. 3. Diagonally-hafted sickle blades, macroscopic and microscopic view of the use-wears. A) Torre Sabea: a1) Marginal resharpening of the edge, 10×; a2) plant-cereal polish, 100×. B) Masseria Candelaro-Structure Q, layer4: b1) See the diagonal distribution of the cereal lustre, 10×; b2) well-developed cereal polish with striations and «comet tail» features, 100×; C) Ex-Palestra GIL: c1) Macroscopic view, 10×. Note the distribution of the polish all over the distal fracture, indicating that the tool has been broken before its use; c2) Microscopic view, 100×. Note the diagonal orientation of the striae with respect to the edge, confirming a diagonal hafting mode.

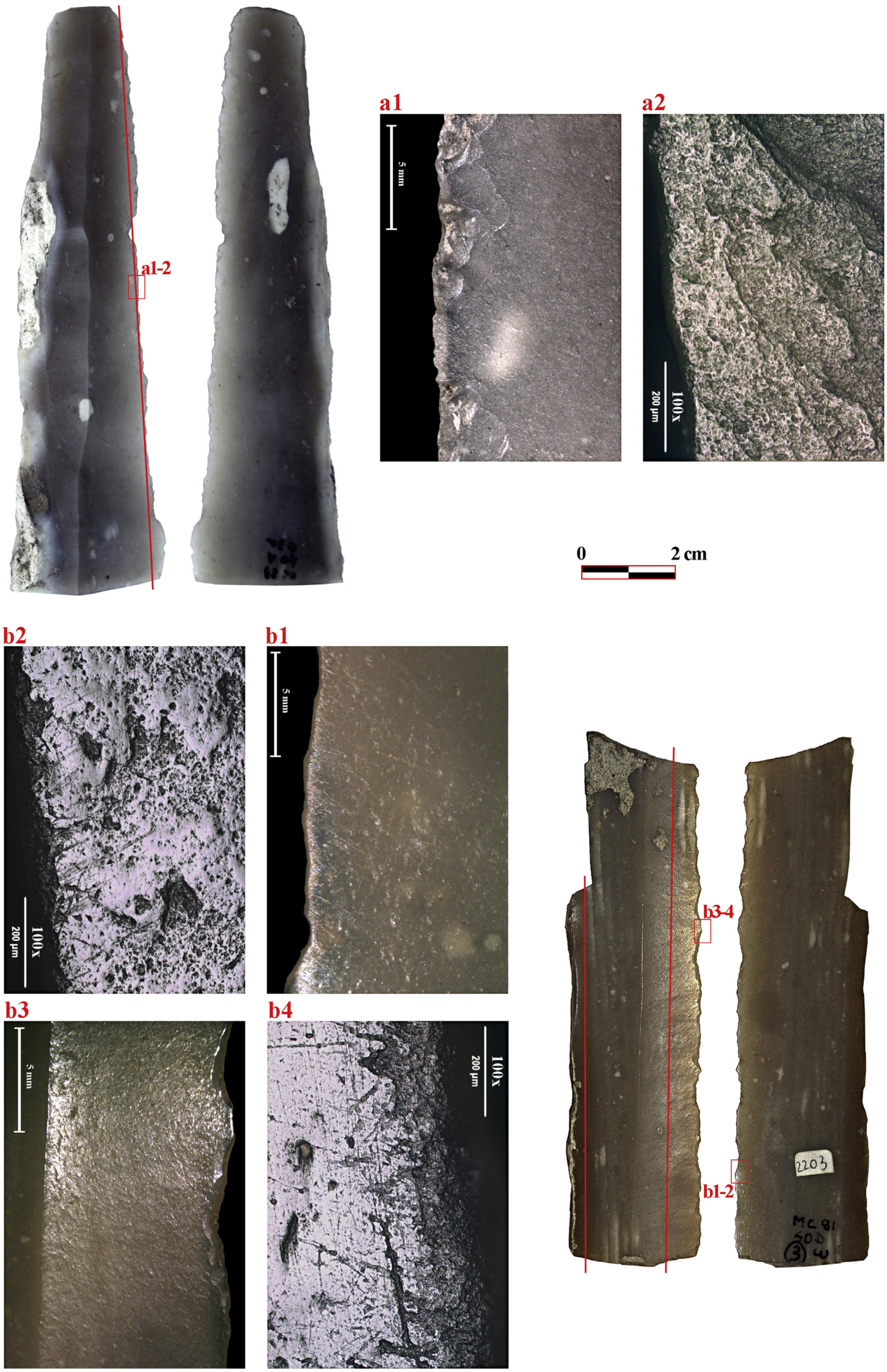

Fig. 4. Long blades used as knives, macroscopic and microscopic view of the use-wears. A) Distal fragment of a long blade from Masseria Candelaro-Structure Q, layer 3: a1) Edge briefly used for gathering plants, 10×; a2) marginal plant polish, 100×; B) Mesial fragment of a long blade from Masseria Candelaro-Structure Q, layer 3. Edges intensively used for harvesting cereals, later retooled for another activity: b1) Left edge, microscopic view, 10×. See how the cereal polish is interrupted by the transversal striae; b2) Same area, macroscopic view, 100×; b3) Right, edge, macroscopic view, 10×. Well-developed cereal gloss; b4) Microscopic view. See how the cereal polish is abraded by the successive transversal activity, 100×.

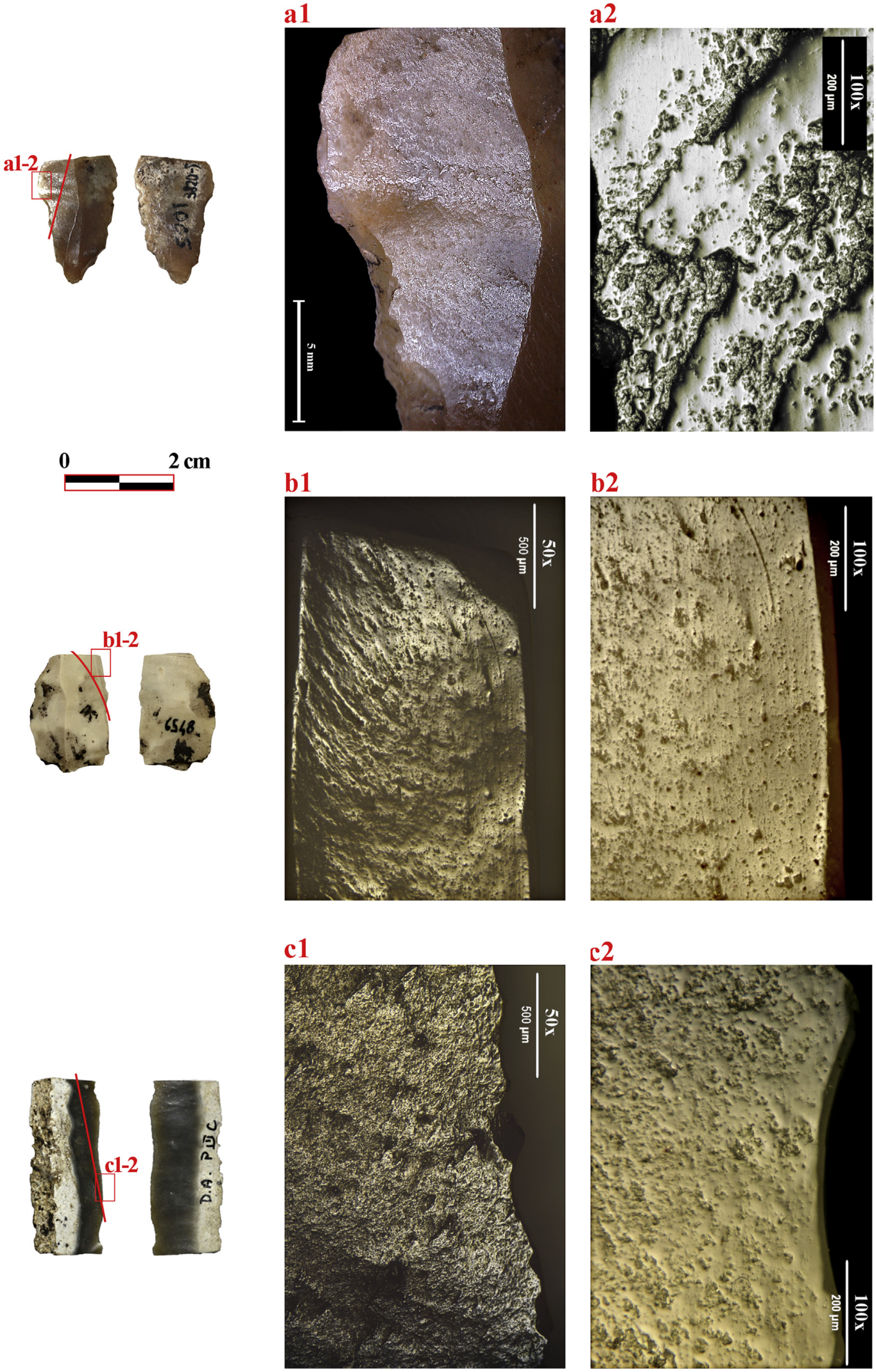

Fig. 5. Diagonally-hafted sickle blades, macroscopic and microscopic view of the use-wears. A) Arene Candide. Sickle insert used on both sides: a1) Cereal gloss, macroscopic view, 10×; a2) plant or cereal polish, 100×. B) Fornace Cappuccini. Sickle insert used on a small angle. See the presence of black spots of bitumen: a1) Rounded angle, well-developed cereal polish, 50×; a2) Same area, 100× magnification. See the presence of striae. C) Sickle insert with a slightly diagonal orientation: c1) See the diagonal distribution of the gloss, 10×; c2) Plant polish, 100×. Note the smoothness of the polish.

homogeneous: diagonally-hafted glossy blades characterize all the analysed sites since the earliest periods (*ca*. 5800–5500 cal BC) (Bermond Montanari et al., 1994; Radi and Danese, 2003; Radi et al., 2005; Fedeli et al., 2009; Fabbri et al., 2011; Mengoli, 2011) (i.e. Cialdino, Fornace Cappuccini, Colle Santo Stefano, Maddalena di Muccia) (Table 1). During the Impressa-Ware phases, inserts were obtained from small blades and bladelets (on average 1.7–2.3 cm long, 0.9–1.3 cm wide, 0.2–0.3 cm thick). They generally show diagonal lustres, with glossy surfaces forming a 30–70° angle with the edges, this suggesting a diagonal position within the haft that also formed a serrated edge (Fig. 5, b). This type of sickle very much resembles those found at the site of La Marmotta, on the shores of Bracciano Lake; inserts of this type are also known in literature from other Impressa sites such as Marcianese (Moroni and Ronchitelli, 1997), Portonovo (Conati Barbaro et al., 2014), Grotta Sant'Angelo (Di Fraia and Grifoni Cremonesi, 1996). Such a hafting mode remained unchanged also in the Red-Painted-Pottery Culture of Catignano, in the Middle Adriatic area (*ca*. 5400–4600 cal BC) (Tozzi and Zamagni, 2003; Colombo et al., 2008) (i.e. Catignano, Colle Cera). Despite that, remarkable is the presence of a long blade on Gargano flint at Colle Cera (Catignano Culture, Abruzzo) with marginal traces related to a quick plant cutting work; this confirms the pattern already observed in South Italy (Fig. 6, a).

Later, during the Late Fiorano and Early-VBQ phases (sites of Mileto and Rivaltella) (Sarti et al., 1991; Tirabassi, 2014), a change is documented in some sites of both the Adriatic and Tyrrhenian sides, with the appearance of parallel hafted blades, as previously observed at Arene Candide. Parallel hafted blades appear slightly wider and thicker (on average 5–6 cm long, 1.5–1.7 cm wide and 0.4–0.5 cm thick); however, the main difference is given by the fact that those blanks were not broken before being hafted, but set into the shaft exploiting their entire length. Parallel hafted blades have also been documented at the site of Cala Giovanna on the island of Pianosa, although in a context of uncertain chronological attribution, between 5300 and 4400 cal BC (Serradimigni, 2007).

In Sardinia, one retouched segment with a well-developed diagonal lustre has been recovered from Su Coloru Cave (North Sardinia). This tool comes from layer H that has been dated to *ca*. 5740–5470 cal BC; however, the radiocarbon dating shows a very large standard deviation. The underlying layer, even if characterized by few material remains, gives a more precise ^{14}C date, 5790–5640 cal BC, and confirms an early occupation of the island by Neolithic groups (Fenu et al., 2012).

4.4. Po plain

In the central-western part of the Po Plain, the Neolithization took place later, around *ca*. 5200–4700 cal BC, with the so-called Vhò-Culture group; no Impressa-Ware sites have been excavated until now in this area. Vhò sites (i.e. Campo Ceresole, Ostiano Dugali, Isorella, Brignano Frascata and Alba) are documented only through pit structures and little is known about settlement organization; however, ceramic and lithic assemblages are extremely homogeneous. Raw material sources are dominated by the Monte Lessini flint, whose exploitation was probably based on exchange networks for supplying preforms and prepared cores from the northern part of the Po Plain (Veneto region) to north-western Italy (Pessina, 2000). Standing pressure technique was probably the main technique, even if larger blades were occasionally produced by indirect percussion.

At Vhò, both types of glossy blades have been discovered: diagonally and parallel hafted elements; however, remarkable differences from one site to another have been observed (Table 1). At Campo Ceresole and Ostiano Dugali (Biagi and Voytek, 1992; Biagi, 1995), in south-southeaster Lombardy, only diagonally-hafted sickle inserts are present; in both sites sickle inserts are made on small blades, broken on the proximal or distal part; selected blanks are not necessarily represented by full-debitage blades with a trapezoidal cross-section, but also by cortical and secondary blades; their measures range between 3.5 and 2.6 cm long, 1.3 and 1 cm wide and 0.4 to 0.3 cm thick (Fig. 5, c). At the site of Alba in Piedmont, diagonally-hafted sickle inserts have been identified as well (Venturino Gambari, 1995), while at Brignano Frascata (D'Amico et al., 2000), in southern Piedmont, together with diagonally-glossed blades showing similar characteristics as those of Campo Ceresole or Ostiano Dugali, slightly larger blades (1.8–1.5 cm wide x 0.5–0.3 cm thick) with glosses distributed parallel to the edges have been detected; amongst them, one complete blade reaches 7.8 cm in length (Fig. 6, b). At Isorella (Starnini, 1998), in south-eastern Lombardy, only parallel hafted sickle inserts of similar size have been recognized. Finally, parallel hafted blades have been recognized also at the waterlogged site of Pizzo di Bodio, in northern Lombardy, from late Early Neolithic and VBQ layers (Lo Vetro et al., 2009).

This situation, with a coexistence of different hafting modes, may be related to the later phase of the Vhò sites, around the end of the sixth and the beginning of the fifth millennium cal BC, a period in which a re-composition of the material package seems to have taken place among North and Central Italy's Neolithic groups, with the emerging of VBQ complexes and diverse influences converging from both north-western and north-eastern regions (Tiné, 1999: 187; Del Santo and Mazzieri, 2014; Tirabassi, 2014). Although this pattern has still to be confirmed by the analysis of more VBQ sites, the appearance of new harvesting tools between the late Early Neolithic and the VBQ Culture was already pointed out by Biagi and Nisbet (1987) about northern Italy (Lombardy and Veneto), suggesting that a change was taking place not only on a local scale, but across a vast area from Liguria to the Adriatic coasts.

4.5. North-East Italy

The Friulian plain, in north-eastern Italy, is a key area for understanding the Neolithization of continental Italy. There, Neolithic communities first settled around 5600–5500 cal BC. As in the rest of North Italy, raw materials are mainly constituted by Monte Lessini flint, probably knapped in specialized ateliers and locally redistributed (Pessina, 2000). At the large sites of Sammardenchia and Piancada (Ferrari and Pessina, 1999), several glossy blades have been detected, none of them showing diagonally-distributed gloss. All the inserts were hafted in a parallel fashion, forming a straight cutting edge (Fig. 6, c). Complete elements are rare as most of them are retooled; however, it seems that inserts' measures were on average 7.5–5.5 × 1.8–1.4 × 0.5–0.3 cm. Mazzucco et al. (2016) interpreted those inserts as being probably hafted in parallel fashion into reaping tools similar to the ones found at La Draga (Palomo et al., 2011). On the basis of the radiocarbon framework from Sammardenchia, it seems that this type of tool characterized the whole occupation; however, the majority and more complete glossy blades come from structures dated to a later phase, between *ca*. 5300–5070 and *ca*. 4730–4450 cal BC (Mazzucco et al., 2016), while for the earliest contexts only very fragmentary specimens were recovered. Further analysis from other Friulian sites will be necessary to confirm this pattern.

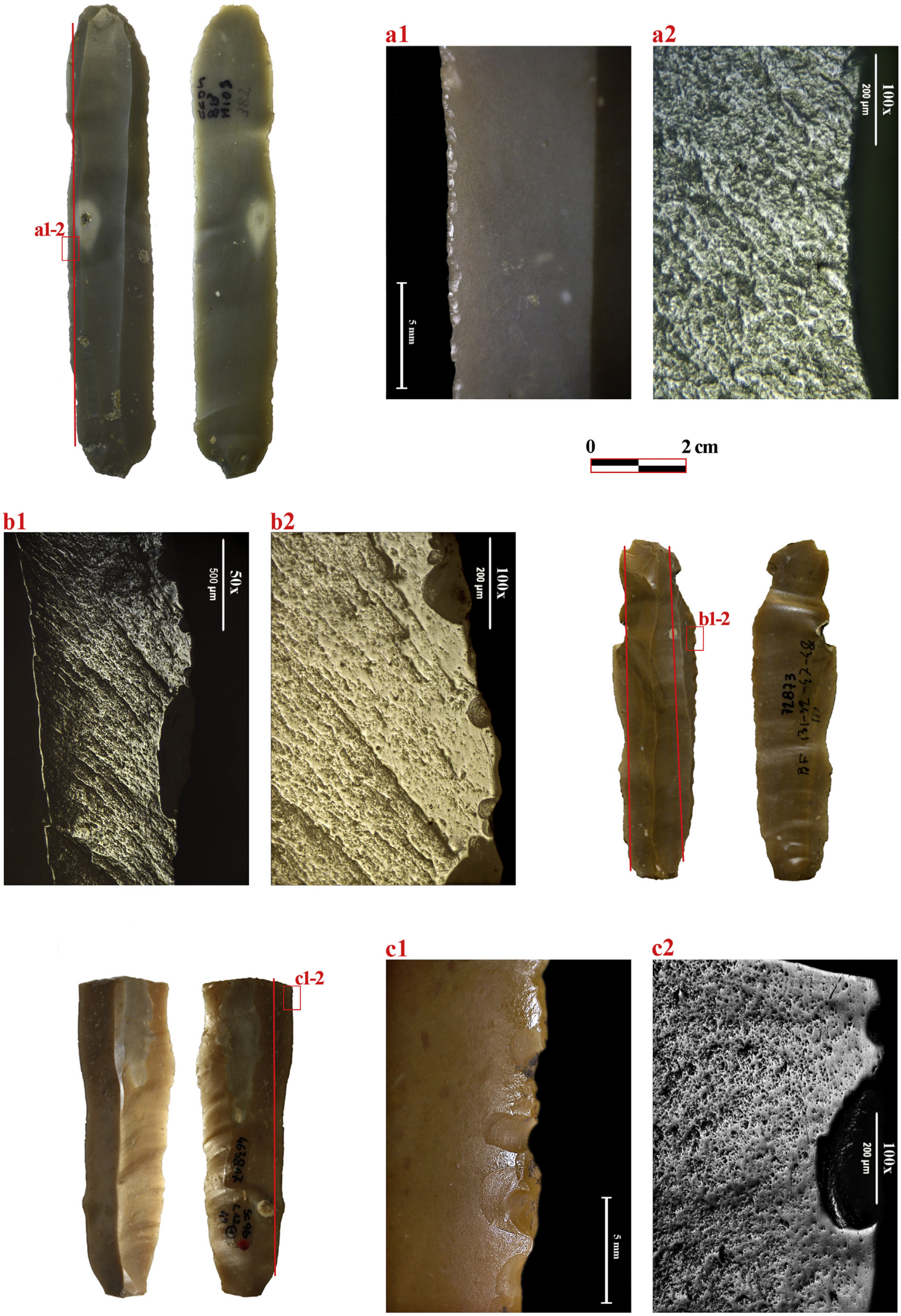

Fig. 6. Parallel hafted blades, macroscopic and microscopic view of the use-wears. A) Colle Cera. Long blade briefly used for cutting plants: a1) Macroscopic view, 10×. Note the absence of a well-developed lustre; a2) Plant polish, 100×. Note the little development of the wears. B) Brignano Frascata. Blade used on both edge for harvesting plants/cereals: b1) Macroscopic view, 10×. See the distribution of the gloss all over the edge, until the dorsal ridge; b2) Plant polish, 100×. Note the smoothness of the polish. C) Sammardenchia. Blade used for harvesting cereals: c1) Macroscopic view, 10×. See the distribution of the gloss, parallel to the edge; c2) Microscopic view, 100×. See how the polish is distributed all over the distal fracture.

5. Discussion

5.1. Harvesting tool production, management and use in the Italian Peninsula

The results obtained in this study have provided hard data to support the existence of at least two different harvesting traditions in Italy: 'curved sickles with dented edges' and 'reaping tools with a straight blade' (Figs. 1 and 2). Curved sickles seem to have their origin in the South. The earliest evidences of those tools are currently known in the Apulian regions; their diffusion towards north largely coincides with the advance of Impressa groups across the Italian peninsula, even if other different pottery groups, such as the Vhò of the Po Plain, shared this same harvesting technique. On the other hand, the earliest dates for the reaping tools with a straight blade currently come from North-East Italy, although the long duration of the settlement of Sammardenchia makes it hard to define a precise chronological framework for their first appearance. A more generalized adoption of those harvesting tools seems possible at the beginning of the fifth millennium cal BC in most parts of North Italy.

One key question that should be addressed is whether the availability of good-quality raw materials had an influence or not in the adoption of one or the other tool. While dented sickles are composed of small inserts, easily obtained by splitting blades or even bladelets, parallel hafted blades are usually made out of wider and larger blanks. Therefore, the availability of nodules of a size suitable for their production might represent a constraint for the adoption of this type of tools. In order to confirm such a pattern, a statistical test can be carried out taking into consideration the maximum width of inserts from South, Central, North and North-East Italy. An experimental work conducted by Pelegrin (2012) has demonstrated how width represents the best measurement for comparing different ways of production by the pressure flaking technique.

Before comparing groups' means, a Levene's test of variance should be carried out to test the assumption of homogeneity of variance. The result of this test ($F = 6.615$, $df = 3$, P: 0.000) indicates that there is a significant difference between the mean widths of the four areas. Since the data is normally distributed, a Welch's ANOVA test can be run. Results indicate that a regional variance in inserts' width effectively exists ($F = 32.443$, $df = 3$, P: 0.000). Using a Games-Howell post-hoc test one can further explore regional differences between the mean values of width. Results indicate that width significantly differs amongst South and North and Central Italy, and amongst North-East and North and Central Italy (Table 2). This means that, while South and North-East Italy show the widest inserts, North and Central Italy are characterized by the narrowest ones, as also clearly inferred from the boxplot (Fig. 7). This data suggests that raw materials had little influence on the adoption of one or the other type of harvesting tools. Indeed, inserts from both North and North-East Italy are made of Monte Lessini cherts, but widths significantly differ between them, being the first mainly characterized by diagonally-hafted blades, while the other ones only by parallel hafted blades. On the contrary, South and North-East Italy's inserts show similar widths despite being characterized by different hafting methods. Sites of South Italy and especially of the Tavoliere are indeed characterized by the exploitation of Gargano chert, which made the flaking of wider blades possible. However, despite the availability of larger blanks, blades were here systematically split into parts and hafted in composite curved sickles. Other factors of a cultural or economic nature played a role in the decision on which hafting method and harvesting technology were to be adopted.

The difference between diagonal and parallel gloss amongst blades is not only due to the modes of hafting and the size of the blades, but also to the technological system involved in their production, management and maintenance. Curved sickles were made with stone inserts which were easily produced by splitting blades, but also bladelets obtained from average-quality cherts. Their production can be considered unspecialized and required little investment for designing/retouching tools. Such blades are generally only marginally resharpened; it was then quicker and easier to replace them with new inserts. In contrast, the management of reaping knives with parallel hafted blades seems to follow a different strategy. Specifically, the employed blanks were mostly full-debitage blades which were initially hafted exploiting their entire length. Those tools were not quickly discarded; edge resharpening was a very frequent technique for prolonging the use of the tool. In this case, it is not the stone insert that was replaced, but its cutting edge. Moreover, not only the management of still used glossy blades was different, but also their management after they were discarded. At Sammardenchia glossy blades appear to have been systematically retooled as scrapers or borers, this indicating that those blades were still technologically and functionally valuable (Mazzucco et al., 2016). On the contrary, the inserts of curved sickles were only rarely retooled; since they originally were small in size, they could not be useful for making new tools.

Finally, tools probably also differed in terms of movement involved in harvesting. Available archaeobotanical data from Impressed-Ware sites of central and southern Italy indicates the common use of agricultural by-products as building elements for constructing walls and making pottery. Impressions by spikelets, glumes and internodes are the most common; however, straws are

Table 2
Games-Howell post-hoc test for the width measurements of the glossy blades from the four macro-regions considered in the text. Significant values are indicated with an asterisk (*). The mean difference is significant at 0.05 level.

Region (I)	(J)	Mean difference (I-J)	Std. Error	Sign.	95% Confidence interval: Lower bound	Upper bound
Central Italy	North Italy	−.89919	.44260	.182	−2.0514	.2531
	North-east Italy	−4,21288 (*)	.54103	.000	−5.6332	−2.7925
	South Italy	−4,84603 (*)	.62343	.000	−6.4699	−3.2221
North Italy	Central Italy	.89919	.44260	.182	−.2531	2.0514
	North-east Italy	−3,31369 (*)	.54975	.000	−4.7576	−1.8698
	South Italy	−3,94684 (*)	.63101	.000	−5.5911	−2.3026
North-east Italy	Central Italy	4,21288 (*)	.54103	.000	2.7925	5.6332
	North Italy	3,31369 (*)	.54975	.000	1.8698	4.7576
	South Italy	−.63315	.70356	.805	−2.4673	1.2010
South Italy	Central Italy	4,84603 (*)	.62343	.000	3.2221	6.4699
	North Italy	3,94684 (*)	.63101	.000	2.3026	5.5911
	North-east Italy	.63315	.70356	.805	−1.2010	2.4673

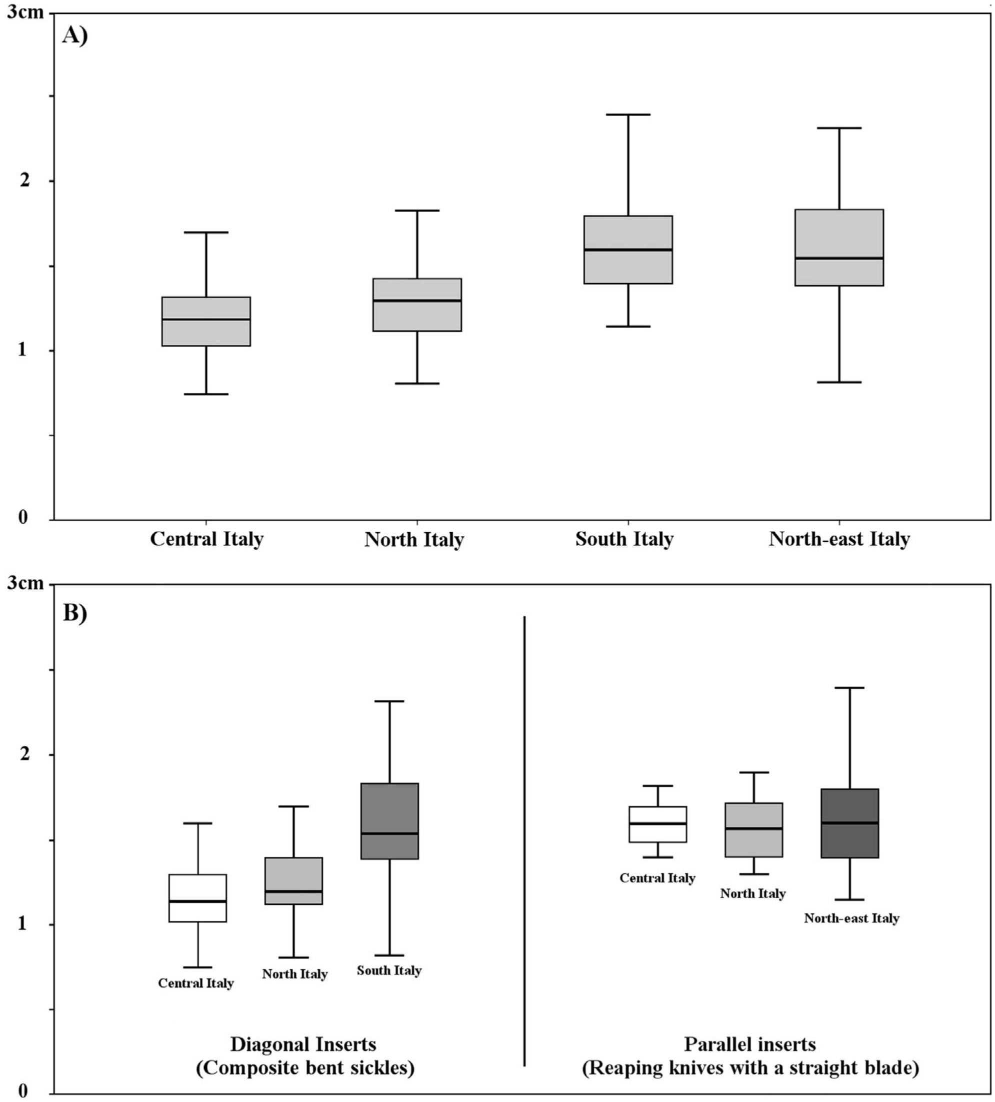

Fig. 7. Boxplot of width measurements of the glossy blades from South Italy, Central Italy, North Italy and North-East Italy. A) Boxplot for both types of harvesting tools; B) Boxplot separated on the basis of the type of harvesting tool. Glossy blade measurements are taken from the following sites: Masseria Candelaro, Passo di Corvo, Masseria Acquasalsa, Masseria Pantano, Ex-Palestra GIL, Fornace Cappuccini, Catignano, Colle Cera, Cialdino, Rivaltella, Alba, Arene Candide, Campo Ceresole, Ostiano Dugali, Isorella, Mileto, Cala Giovanna, Piancada, Sammardenchia, Pizzo di Bodio.

represented as well. Besides, the presence of low-growing species such as *Euphorbia helioscopia* (sun spurge) in several Early Neolithic sites characterized by curved sickle with diagonal inserts suggests a technique of cutting at a low height, possibly for collecting straw. For example, at Torre Sabea impressions of *Euphorbia helioscopia* have been ascertained on wattle and daub fragments in association with other by-products such as chaff, spikelets and broken grains derived from crop cleaning and processing activities (Marinval, 2003). At Catignano and Coppa Nevigata, seeds of *Euphorbia helioscopia* have been recovered together with cereal remains from structures interpreted as silos (Costantini and Stancanelli, 1993; Costantini, 2003). This suggests that weeds were brought to the site together with the harvested crops and not intentionally gathered. Despite the fact that the charred seed remains often amount to few specimens and a detailed study of the crop weed assemblages is actually lacking in most of the Italian Neolithic sites, this scenario is consistent with the information obtained from the south of the Iberian Peninsula and suggests a cutting at a low height about the La Marmotta-type sickles. On the other hand, data from Sammardenchia seems in accord with information from La Draga; low-growing species are absent and, more generally, the crop weed assemblage is not abundant, this suggesting that few weeds were gathered with cereals. Moreover, the presence of climbing weeds such as *Fallopia convolvulus* (black bindweed) (Rottoli, 1999) in several refuse pits in association with charred crop remains suggests an ear harvesting technique (see also Bogaard, 2004: 60).

5.2. *Diffusion of harvesting technology: curved sickles with dented edge*

In previous papers a diffusion of curved sickles following a maritime route has been proposed (Ibáñez et al., 2017). However, the model was based on a qualitative observation of the radiocarbon dataset relevant to the sites where harvesting tools were detected. In this paper, in order to adopt a more rigorous approach, a kriging interpolation method has been employed.

Sites considered in the analysis are shown in Table 3. The degree of relationship between the 20 georeferenced ^{14}C dated archaeological contexts and the Earth's terrestrial surface is expressed by the semivariance. The obtained Whittle semivariogram for the

Table 3
Data used for Empirical Bayesian Kriging. Sites characterized by diagonally-hafted sickle inserts.

ID	Site	Lab code	14C Age BP	±	Median	Material and archaeological context	Reference
1	Alba	GX-20845	6030	80	−4934	Charcoal, US 72/A	Venturino Ganbari et al., 1995
2	Arene Candide	Beta-110542	6830	40	−5711	Hordeum v., Lay. 27	Biagi and Starnini 2016
3	Bajondillo	Wk-27461	6234	30	−5225	Ovis aries, n/a	Isern et al., 2014
4	Cialdino	n/a	6460	35	−5422	Charcoal, n/a	Fedeli et al., 2009
5	Coppa Nevigata	OxA-1475	6880	90	−5777	Hordeum v., top of enclosure ditch	Costantini and Stancanelli 1993
6	Mas d'Is	Beta-16672	6600	50	−5547	Hordeum v., Lower Hut	Bernabeu et al., 2009
7	El Barranquet	Beta-221431	6510	50	−5478	Ovis aries, U.S. 79	Bernabeu et al., 2009
8	Fornace Cappuccini	Bln-3372	6320	60	−5303	Charcoal, Lower sector of the ditch	Mengoli 2011
9	Guixeres de Vilobí	OxA-26068	6655	45	−5582	Ovis aries, Lay. A	Oms et al., 2014
10	La Marmotta	R-2360	6855	65	−5744	Charcoal, $P2_13$	Fugazzola Delpino et al., 1993
11	Maddalena di Muccia	R-643a	6580	75	−5535	Charcoal, Pit.S, cut 4−6, cavity 5	Improta and Pessina 1999
12	Muercielagos de Zuheros	Beta-316509	6200	40	−5143	Hordeum v., Phase A/U.S.80	Carvalho et al., 2012
13	Cueva Nerja	OxA-26085	6342	37	−5326	Ovis aries, NM10	García Borja et al., 2014
14	Peiro Signado	Ly-8400	6840	55	−5724	Charcoal, Str. 7	Philibert et al., 2014
15	Colle Santo Stefano	LTL-60A	6843	40	−5723	Charcoal, S.S.2000	Fabbri et al., 2011
16	Su Coloru	n/a	6680	160	−5610	Charcoal, Lay. H	Fenu et al., 2012
17	Torre Sabea	Gif-88066	6960	130	−5849	Cereal grain, Layer C2c, Pit T-U/11-12	Guilaine and Cremonesi 2003
18	Trasano I	TAN-88248	6980	130	−5865	Charcoal, Lay. C.3	Manen and Sabatier 2003
19	Vale Pincel I	Beta-164664	6740	40	−5654	Pinus pinea, Str. 8	Soares et al., 2016
20	Campo Ceresole	I-11445	6170	110	−5114	Charcoal, Pit feature XVIII	Biagi and Voytek 1992

curved sickles is shown in Fig. 8; the x-axis displays distances among observed points, the y-axis, in turn, indicates their semivariance. The visible nugget effect is a consequence of the variance at the origin and it is influenced by many factors, including imprecision in sampling techniques and underlying variability of the measured attribute. In our graph, the small value obtained for the nugget effect could suggest a local homogeneity (Brami and Zanotti, 2015). The sill refers to the maximum observed variability in the data and it should correspond to the variance of the data as usually estimated in statistics. The distance where the model first flattens out is known as range. Sample locations separated by distances closer than the range are spatially autocorrelated, whereas locations farther apart than the range are not.

An interpolated map with the diffusion of the diagonally-hafted blades across space and over time has been produced on the basis of the selected values from the 20 ^{14}C dated contexts (Fig. 9). The statistical results show that the diffusion of this kind of sickle is characterized by a distinctive space-time gradient. Oldest dates are located in the south-eastern part of the Italian Peninsula, corresponding to the region of Apulia; in this area, the adoption of such technology can be dated to the ninth century of the fifth millennium BC. From this region, the harvesting technologies would have expanded to the North, North-West and West. Northern Italy, southern France and the southern façade of the Iberian Peninsula appear to be areas where the curved sickles are characterized by a more recent chronology; the adoption of this specific kind of tool took place approximately 600/700 years later in the Po Valley, in northern Italy, as well as in Andalusia, in southern Spain.

It is meaningful to highlight that the model suggests a maritime colonization for the introduction of this type of harvesting technology in the territories corresponding to the French coast facing the Gulf of Lion and in the Catalan-Valencian area, which would correspond to the so-called pre-Cardial groups (Bernabeu et al., 2009). Therefore, the model is in good agreement with the classical hypothesis of the diffusion of small pioneer groups across the Western Mediterranean area (Guilaine, 2000).

Nevertheless, it should be remarked that the wave-of-advance (Ammerman and Cavalli-Sforza, 1971) does not probably represent the best model to study the diffusion of the harvesting technologies, as a more complex set of phenomena were taking place. Together with a more gradual demic diffusion, as it seems visible for example in central and Adriatic Italy, long-distance maritime dispersal events were happening. Those events are not well-represented by the model, for example when 'pioneer' and 'later' sites are located within the same or neighbouring regions, as in the case of the sites of Arene Candide and Alba (Fig. 9). This is even more evident when looking at the cross-validation graph (Fig. 10), which compares the measured and predicted values for all points. Each point of the cross-validation graph represents a location in the ^{14}C data, for which an actual and estimated value is available. The Root Mean Square Standardized Error is a measure of the goodness of fit; the obtained value of 0.98 is very close to 1, then it follows that the predicted standard errors are valid. Here, Alba and Arene Candide (points 1 and 2) are situated away from the line, showing a large chronological difference for the first occurrences of curved sickles, but relatively contiguous spatial locations. Finally, it should be stated that Vale Pincel I shows too ancient dates to fit in with this model; this might be due to a problem in the radiocarbon

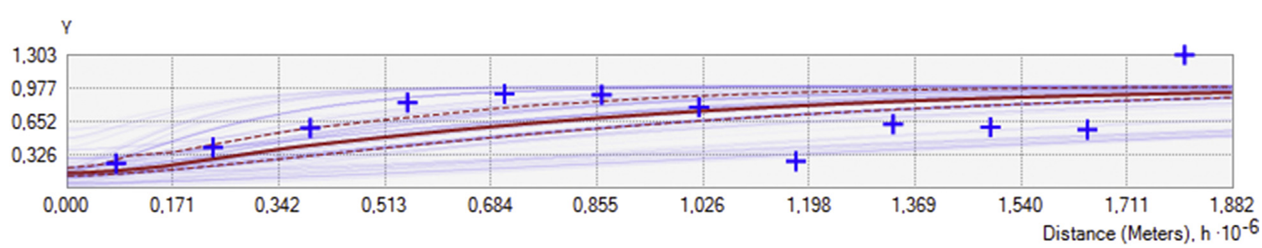

Fig. 8. Spectrum of the distribution of semivariograms produced by the Empirical Bayesian Kriging for the curved sickles. The empirical semivariances are represented by blue crosses, the median of the distribution is marked by a solid red line, and the 25th and 75th percentiles are marked by red dashed lines (Software: ArcGIS 10.3). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

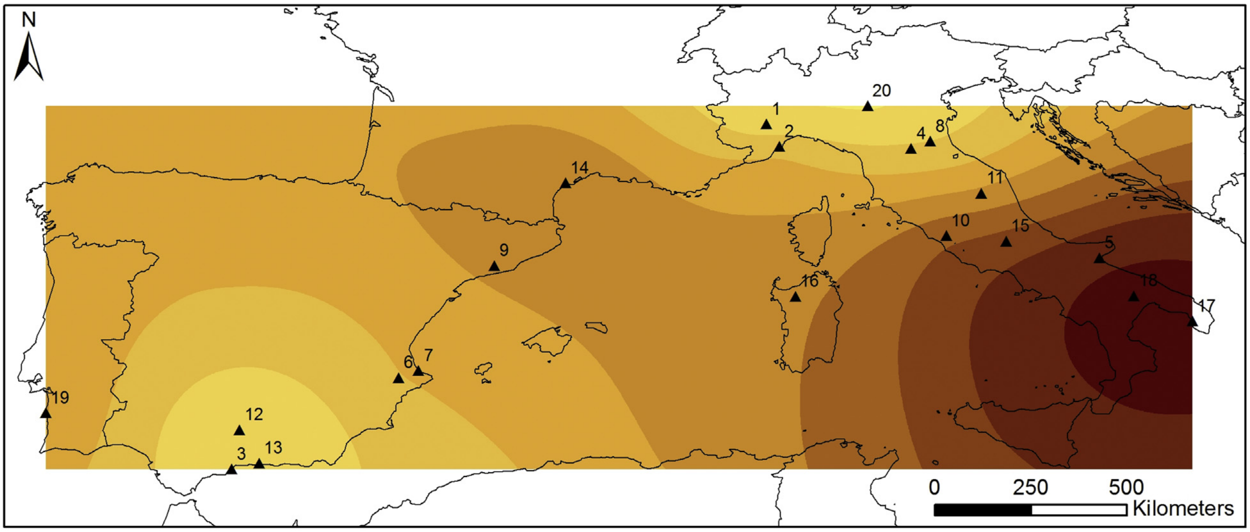

Fig. 9. Interpolated map showing the spatial and temporal variations in the first occurrence of curved sickles in the western Mediterranean area (Software: ArcGIS 10.3). The numbers correspond to the ID numbers of the dataset at Table 3.

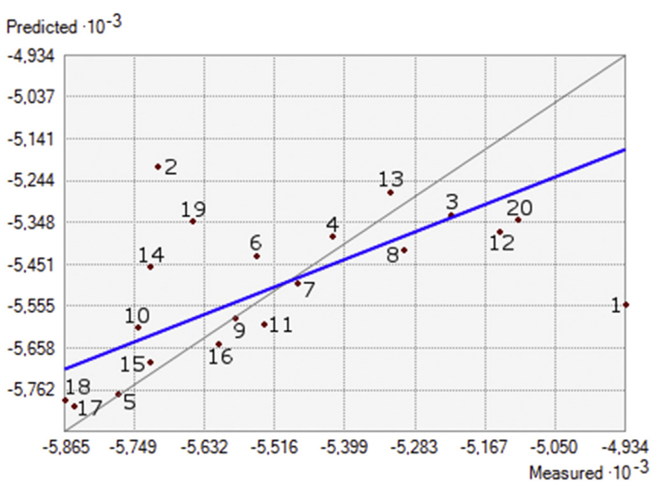

Fig. 10. Cross-validation graph for the Empirical Bayesian Kriging (Software: ArcGIS 10.3).

framework or, otherwise, to different paths of expansion involving northern Africa (Isern et al., 2014), which, however, have not yet been demonstrated.

In conclusion, the wave-of-advance model can only partially explain the diffusion of the harvesting technologies; the paths and rhythms of diffusion probably varied considerably depending on regions' physiography, form of dispersal (inland and/or maritime) and, possibly, on other social factors that we are not yet fully able to discuss (Skeates, 1999; Bocquet-Appel et al., 2009; Guilaine, 2013).

6. Conclusions

In this paper we have presented the state of research on the harvesting technologies of the first farming communities, combining the outcomes of several international projects. New data has been collected covering a large geographical area and completing the picture of Neolithic harvesting techniques for the central and western Mediterranean regions. We believe that this paper demonstrates how the study of harvesting tools can strongly contribute to the understanding of the Neolithic diffusion process, providing fresh data on how interactive and evolved Neolithic groups spread across the Mediterranean area. Although more data is needed, a large amount of important information has been gathered, this allowing us to put forward first hypotheses about the diffusion and evolution of harvesting technology. At least two different harvesting traditions existed: one characterized by curved sickle used for cutting at a low and middle height; the other characterized by reaping knives with parallel hafted blades, mainly used for harvesting ears. Other tools related to the gathering of plants have been identified, too, especially in South Italy, but they are not interpreted as specialized crop harvesting tools; they appear to have been used in a variety of tasks and only occasionally for cutting cereals.

An east-west space-time gradient is clearly visible in the diffusion of curved sickles, with rapid maritime dispersals across the Tyrrhenian Sea and the Gulf of Lion. On the other hand, the origins and diffusion of parallel hafted blades are still debated and more sites are needed to clarify their geographical and chronological distribution. In this respect, it will be important to explore the relationship between North/North-East Italy and the Dalmatian-Istrian regions during the Impressa phases as well as the later Danilo/Vlaska periods. As we are making progress thanks to new researches, including more sites and extending the geographical reach, a more detailed picture is emerging, together with new ideas and new questions. The diffusion of harvesting technologies seems to have undergone changes and innovations during the expansion process, not following a linear expansion, but rather an 'arrhythmic' model of expansion (Guilaine, 2000), which consisted of slowdowns, contact zones, transfers and reworking of techniques.

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