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ORIGINAL PAPER

Multiproxy approach to the study of Medieval food habits in Tuscany (central Italy)

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Abstract A multiproxy approach based on archaeobotanical, organic residue and isotopic analyses was carried out on materials from 12 Medieval archaeological sites in Tuscany (central Italy), in order to provide a diachronic overview of local diet in rural and urban sites from the mid-eighth to the fourteenth centuries AD. Archaeobotanical analyses were applied to 130,578 seeds/fruits, residue analyses involved 87 samples from cooking and storing vessels, whereas analyses of carbon and nitrogen stable isotopes included 63 human bone samples and 26 animal specimens. The results indicate that from the mid-eighth century AD, crop production was of high quality similar, to that of the Roman Age. The main cultivations were naked wheats, barley and horse bean, a diversity that attests the technological skills reached by Tuscan peasants during the whole Middle Ages. Different cereals and pulse abundantly supplemented the diet. This strategy not only ensured peasants' subsistence in the mid-eighth century AD, minimizing the risks of environmental adversities, but it also increased crop production – from the mid-ninth century AD on, for the revived markets and trade. Between the eleventh and fourteenth centuries AD, C4 plants had a dominant role in the peasants' diet, when the wheat production was strictly collected first by the landlords and then by the cities for their own needs. Crop production was integrated by swine farming; animal meat consumption is well documented in rural and urban populations from the ninth century AD. Wine and olive oil, considered important elements of diet in Medieval Tuscany, have a very scarce presence, but they are recorded for later periods, mainly in urban areas and in higher social classes, such as the religious and aristocratic ones. In fact, only between the twelfth and thirteenth centuries AD was the great expansion of olive groves and vineyards recorded, when cities and urban populations claim to have access to these luxury foods.

Keywords Alternative crops · Archaeobotany · Bread-making wheats · C4 plants · Diet · Isotopic analysis · Oil and wine · Organic residue analysis · Quality · Swine farming

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Introduction

In the debate between historical sources and archaeological data on plant husbandry and diet of Medieval populations, analyses of charred plant remains from archaeological sites are crucial to describing the history of food traditions and the agrarian economic system (Rottoli 2014; Ruas 2005). On the other side, the preservation of organic residues in ceramic vessels, used for the production, preparation, storage and consumption of food, provides evidence of the production and consumption of oil and wine as well as of the preparation of animal origin products (Evershed 2008; Garnier 2007; Nigra et al. 2015; Pecci et al. 2013a, b; Regert 2011). Finally, for several years now, the study of human osteological remains has been able to take advantage of chemical-physical methods to study the dietary habits of ancient populations through isotopic mass spectrometry, based on the measurement of isotopic ratios of carbon and nitrogen (Ambrose 1993; Criss 1999; De Niro 1985; Pate 1994; Sealy

2001). In this paper, we present the results of a multiproxy approach to provide a diachronic overview of Middle Age Tuscany (central Italy). In particular, we focus our attention on 12 archaeological sites distributed across Tuscany dated from the eighth to the fourteenth centuries AD (Fig. 1).

Archaeological and historical settings

For central Italy, historians have always considered medieval farming economy as backward in comparison with the preceding Roman economy. The demographic crisis and the reduction in trade that followed the end of the traditional Roman economic system at the end of the fifth century AD fostered the presence of depopulated settlements and ever-more "ruralized" cities (Francovich and Hodges 2003; Ward-Perkins 2005), imposing systems of mere self-sufficiency involving the use of local resources (Montanari 1979).

The diffusion of a new attitude towards the spread of uncultivated lands led to the formation of a mixed productive system of agricultural, livestock and woodland activities, stimulating food practices that involved the consumption of abundant animal origin products. On the other side, the low technology level in agriculture caused the decline of wheat cultivation, the spread of a wide variety of crops to avoid the consequences of poor harvests and the collecting of wild plants and fruits (Andreolli 1981; Cortonesi 2002; Montanari 1979, 2002).

Archaeological sources suggested that the transition between the Late Roman Age and the beginning of the Early Middle Age (sixth to mid-eighth centuries AD) is characterized in Tuscany by the spread of the villages on the hilltop (Valenti 2004). In these settlements, the absence of storage buildings for crops indicates a domestic and subsistence organization of crop production (Bianchi and Grassi 2012). Furthermore, historical sources showed that local aristocracy did not interfere with the villages' economic choices and the management of agricultural resources (Wickham 2005).

According to archaeological data, starting in the mid-ninth century AD, settlements acquired the character of manorial courts diffused by the Carolingian economic system, epoch in which the landlords began to control the economies of the villages and to manage the lands with a new farming system (Wickham 2005). The manorial system (in Italian, the *sistema curtense*) was characterized indeed by the 'bipartite' division of an estate into a demesne and tenant holdings. The demesne on a manor was worked and cultivated by the labour service of tenants, in particular free peasants, as part of their rent. In Tuscany, archaeological sources show that manorial courts were defended by walls made of wood or stones, which surrounded the top of the hills. In fact, here, large warehouses were built in order to concentrate the landlord's crop production (Bianchi and Grassi 2012).

From the mid-ninth to the eleventh centuries AD, several sites in Tuscany present further changes in the material culture, along with an evolution towards castles in which walls

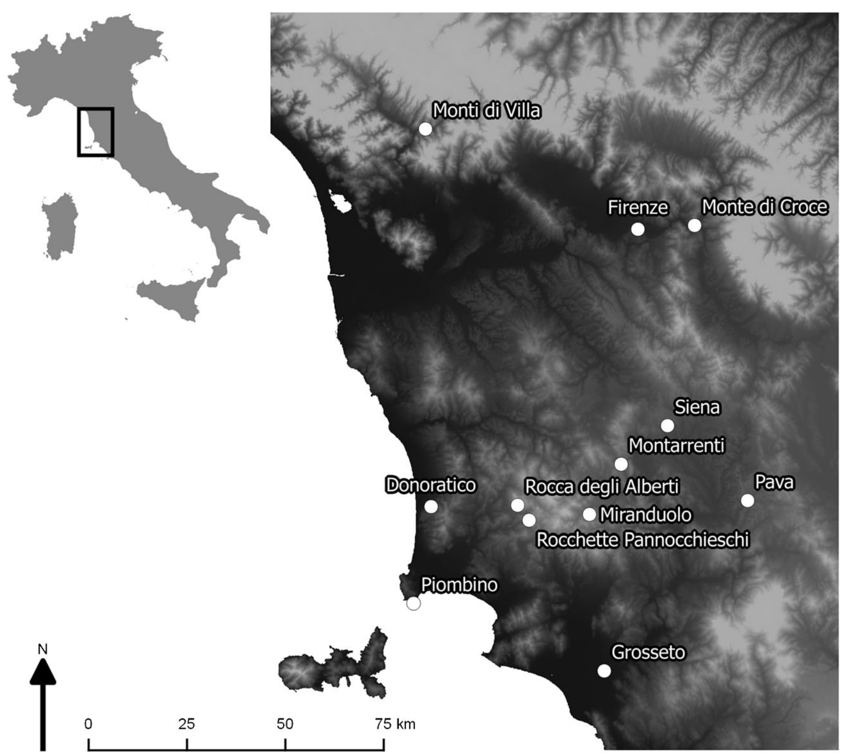

Fig. 1 Location of the studied sites

were rebuilt and enclosing wooden and stone buildings were constructed (Bianchi and Grassi 2012).

Finally, starting in the eleventh century AD, which is considered the beginning of the Late Middle Ages, a new economic organization arose with the establishment of the political system of the towns and *Communi*. This led to the creation of market places in order to satisfy the rising demand for food and luxury products (Wickham 1988).

Within this broad historical framework, this paper aims at providing evidence of the food procurement and consumption in different sites and periods in Medieval Tuscany.

Materials and methods

Archaeobotanical analysis

This archaeobotanical study takes into account different sites with different characteristics (Table 1). In particular, four Early Medieval rural settlements (Montarrenti, Rocca degli Alberti, Miranduolo and Rocchette Pannocchieschi) located in the core of the so-called Metalliferous Hills, between 350 and 540 m a.s.l. (Fig. 1), are considered (Buonincontri et al. 2013, 2014; Cantini 2003; Pescini and Aniceti 2014), along with one Late Medieval urban site, Florence, located in the plain of the River Arno (Fig. 1; Buonincontri et al. 2007, 2009). Radiocarbon and/or pottery analyses date the Early Middle Ages layers between the mid-eighth to the eleventh centuries AD, whereas the Late Middle Ages layers pertain to the thirteenth century AD.

The samples came from excavations of rubbish and storage pits, burnt warehouses and huts and ovens (Table 1). Most carpological remains were charred after fires; only samples from Florence yielded waterlogged (fruits and vegetables) and carbonized (cereals and pulses) remains.

The richness and variety of plant remains in the samples is due to differing archaeologists' sampling methods and standards. With the exclusion of Montarrenti, in which the counting has not been defined, the volume per soil sample ranges from 2 to 60 l. All the samples were processed with an 'Ankara'-type flotation machine equipped with a 0.5-mm mesh in the floating tank. Once floated out, macroremains were recovered using mesh sizes 4, 2, 1, 0.50 and 0.25 mm.

Following the evolution of the sites as suggested by the material culture and the archaeological excavations, samples are split into five cultural periods (Table 2). A total of 130,578 remains of crop plants are classified. The site of Montarrenti yielded abundant material, but counting has not been finalized yet, while Rocchette Pannocchieschi provided very few remains. Vegetables and fruits are underrepresented, while they were better preserved in the waterlogged layers of Florence. Cereals and pulses, on the other hand, are better represented in all the sites due to their charred condition.

In Fig. 2, it is possible to observe the percentages for each taxon of cereals, pulses and fruits, considering only the individuals; we use the term 'individual' when the fragments had diagnostic features that allowed us to count them as entire. However, when only fragments are available for specific taxa, all of them are considered.

The seeds of *Lathyrus sativus* and *L. cicera* are hardly distinguishable if preserved by charring. The character used in the charred seeds to differentiate between the two species was the position of the small oval hilum, placed at one corner between two 'faces' in L. *sativus*, but on one face in *L. cicera* (Renfrew 1973; Sadori and Susanna 2005).

Residue analysis of ceramic vessels

Residue analysis of ceramic vessels involves samples from cooking vessels and tableware from Tuscan archaeological sites ranging from the ninth to the fourteenth centuries AD (Table 3). Specifically, the samples analysed came from the cities of Siena, Firenze, Piombino and Grosseto and the rural settlement of Donoratico (Fig. 1; Baccarini 2007; Buonincontri et al. 2007; Giorgi et al. 2010; Pecci 2009, 2015, unpublished work; Pecci and Salvini 2007; Salvini et al. 2008).

Table 1 List of the five archaeobotanical sites with detailed information

Site	UTM X (Easting)	UTM Y (Northing)	Elevation	Type of settlement	Type of feature	Type of preservation	Centuries AD	Total of crop plant remains
Florence	681,599	4,848,636	47	Urban quarter	Rubbish pits, house floors	Waterlogged and charred	13th	22,069
Montarrenti	677,295	4,789,010	354	Rural settlement	Warehouse, hut floor, oven	Charred	Mid-8th–11th	Not counted
Rocca degli Alberti	650,995	4,778,560	538	Rural settlement	Warehouse, storage pits, ovens	Charred	Mid-8th–end 10th	10,330
Miranduolo	669,241	4,776,223	410	Rural settlement	Warehouses, storage pits, hut floors	Charred	Mid-8th–11th	97,949
Rocchette Pannocchieschi	653,908	4,774,733	447	Rural settlement	Hut floor	Charred	End 10th–11th	230

UTM zone is 32T; elevation is expressed in m a.s.l.

Table 2 Number of remains of crops and fruits in different sites according to the Medieval chronologies and cultural periods of Tuscany

Chronology, century AD		Mid-8th–mid-9th		Total	Mid-9th–end 10th			Total	End 10th–11th			Total	13th	Total
Cultural period		Villages			Manorial courts				Castles				Communi	
Archaeological site		Miranduolo	Rocca degli Alberti		Montarrenti	Rocca degli Alberti	Miranduolo		Montarrenti	Miranduolo	Rocchette Pannocchieschi		Firenze	
Cereals														
Avena sp.	Grains	47	221	268		15	88	103		196		196	62	62
Avena sp.	Grain frg						20	20		5		5	12	12
cf. *Avena*	Grains	2	5	7			28	28		96		96	3	3
cf. *Avena*	Grain frg						1	1						
Hordeum vulgare	Grains	16	943	959	x	8	1238	1246	x	2994	3	2997	206	206
Hordeum vulgare	Grain frg						20	20		86		86	24	24
cf. *Hordeum vulgare*	Grains						40	40		154		154		
Hordeum/Triticum	Grains					2		2						
Hordeum sp.	Grains		39	39										
Panicum miliaceum	Grains	28		28			252	252		906		906	1306	1306
Panicum miliaceum	Light chaff frg												12	12
cf. *Panicum miliaceum*	Grains						54	54		27		27		
Panicum/Setaria	Grains						4	4						
Secale cereale	Grains	2	22	24		3	1739	1742		8782		8782	97	97
Secale cereale	Grain frg						8	8					14	14
cf. *Secale cereale*	Grains						59	59		1029		1029		
Setaria italica	Grains		29	29	x	14	215	229	x	193		193	8	8
cf. *Setaria italica*	Grains						4	4						
cf. *Sorghum bicolor*	Grains				x		2	2	x					
Setaria/Sorghum	Grains						3	3						
Triticum aestivum/durum	Grains	200	4031	4231	xxx	2097	13,880	15,977	xx	11,552	208	11,760	2351	2351
Triticum aestivum/durum	Grain frg						1	1			5	5	19	19
Triticum cf. *aestivum/durum*	Grains	6	6	12			244	244		253		253		
Triticum cf. *aestivum/durum*	Grain frg						2	2						
Triticum dicoccum	Grains	1	206	207			114	114		300		300	445	445
Triticum dicoccum	Grain frg						1	1					7	7
Triticum dicoccum	Spikelets												1	1
Triticum dicoccum	Rachis frg						33	33		72		72	46	46

Table 2 (continued)

Chronology, century AD		Mid-8th–mid-9th		Total	Mid-9th–end 10th			Total	End 10th–11th			Total	13th	Total
Triticum dicoccum	Lemma bases												6	6
Triticum cf. *dicoccum*	Grains	11		11			33	33		185	1	186	1	1
Triticum monococcum	Grains	109	64	173	xxx	3	324	327	xxx	1657		1657	93	93
Triticum monococcum	Grain frg	1		1			1	1					2	2
Triticum monococcum	Rachis frg	1		1			97	97		502		502	33	33
Triticum monococcum	Lemma bases												12	12
Triticum cf. *monococcum*	Grains	6		6			37	37		167		167	6	6
Triticum dicoccum/monococcum	Grains									220		220	16	16
Triticum spelta	Grains						5	5					83	83
Triticum cf. *spelta*	Grain frg						1	1						
Triticum dicoccum/spelta	Grains						4	4		25		25		
Triticum sp.	Grains	44	1436	1480		920	270	1190		699		699	660	660
Triticum sp.	Grain frg	1		1									866	866
Triticum/Secale	Grains						26	26		1487		1487		
Cereals undiff.	Grains	11		11			1124	1124		3147		3147		
Cereals undiff.	Grain frg	115		115			3267	3267						
Pulses														
Cicer arietinum	Seeds									22		22		
Lathyrus cicera	Seeds						17,322	17,322		33		33		
Lathyrus cf. *cicera*	Seeds						7702	7702		114		114		
Lathyrus sativus	Seeds		17	17		3	4294	4297		6		6		
Lathyrus cf. *sativus*	Seeds						1795	1795					4	4
Lathyrus cf. *sativus*	Seed frg												1	1
Lathyrus sp.	Seeds	5	3	8		1	298	299		20	1	21		
Lathyrus sp.	Seed frg						181	181						
cf. *Lathyrus*	Seeds		3	3			1	1						
cf. *Lathyrus*	Seed frg						1	1						
Lens culinaris	Seeds						2	2			3	3		
Pisum sativum	Seeds		1	1							4	4	4	4
Pisum sativum	Seeds frg												1	1
cf. *Pisum sativum*	Seeds	1		1			3	3		4		4	5	5
Pisum/Vicia	Seeds												3	3

Table 2 (continued)

Chronology, century AD		Mid-8th–mid-9th		Total	Mid-9th–end 10th		Total	End 10th–11th		Total	13th	Total
Pisum/Vicia	Seed frg										17	17
Vicia ervilia	Seeds	1		1		16	16	33		33		
Vicia cf. *ervilia*	Seeds								1	1		
Vicia faba var. *minor*	Seeds	7	52	59		4498	4498	1973		1973	48	48
Vicia faba var. *minor*	Seed frg					168	168	55		55	31	31
Vicia cf. *faba var. minor*	Seed frg					191	191					
Vicia sativa	Seeds		11	11					1	1	2	2
Vicia cf. *sativa*	Seeds					4	4	110	3	113	7	7
Vicia sp.	Seeds		3	3		2	2					
Pulses undiff.	Seeds	2	15	17		35	35	96		96		
Pulses undiff.	Seed frg					19	19	143		143		
Vegetables												
Citrullus lanatus	Seeds										9	9
Citrullus lanatus	Seed frg										2	2
Cucumis melo	Seeds										1	1
Cucumis melo	Seed frg										1	1
Cucumis sativus	Seeds										5	5
Cucumis sativus	Seed frg										1	1
Oil/fiber plants												
Linum usitatissimum	Seeds		139	139	7		7					
Fruits - 7 taxa												
Castanea sativa	Seeds					19	19	10		10		
Castanea sativa	Seed frg					1	1	4		4		
Castanea sativa	Pericarp frg										29	29
Corylus avellana	Shell frg										7	7
Ficus carica	Pips										11,422	11,422
Ficus carica	Pip frg										344	344
cf. *Ficus carica*	Syconiums					3	3					
Juglans regia	Shell frg					1	1	3		3	1	1
cf. *Malus* sp.	Seed frg							4		4		
Malus/Pirus	Seeds										28	28
Malus/Pirus	Seed frg										35	35
Olea europaea	Fruitstones		1	1								

Table 2 (continued)

Chronology, century AD		Mid-8th–mid-9th		Total	Mid-9th–end 10th		Total	End 10th–11th		Total	13th	Total
Olea europaea	Fruitstone frg										5	5
cf. *Olea*	Fruitstone frg										1	1
Prunus avium	Fruitstones										357	357
Prunus cf. *avium*	Fruitstones										11	11
Prunus cf. *avium*	Fruitstone frg										110	110
Prunus cerasus	Fruitstones										90	90
Prunus avium/cerasus	Fruitstones							13		13		
Prunus avium/cerasus	Fruitstone frg										18	18
Prunus domestica ssp. *domestica*	Fruitstones										8	8
Prunus domestica ssp. *insititia*	Fruitstones										29	29
Prunus domestica	Fruitstone frg										2	2
Prunus cf. *domestica*	Fruitstones										4	4
Prunus cf. *domestica*	Fruitstone frg										43	43
Prunus persica	Shells					4	4	3		3		
Prunus persica	Shell frg					1	1	4		4		
Prunus cf. *spinosa*	Fruitstones										1	1
Prunus cf. *spinosa*	Fruitstone frg										94	94
Vitis vinifera	Pips		5	5	5	33	38	34		34	2782	2782
Vitis vinifera	Pip frg					18	18				96	96
Vitis vinifera	Pedicels										19	19
Vitis vinifera	Stalk frg					63	63					
Total number by archaeological sites		617	7252	7869	3078	59,914	62,992	37,418	230	37,648	22,069	22,069

xxxx very abundant, *xxx* abundant, *x* few

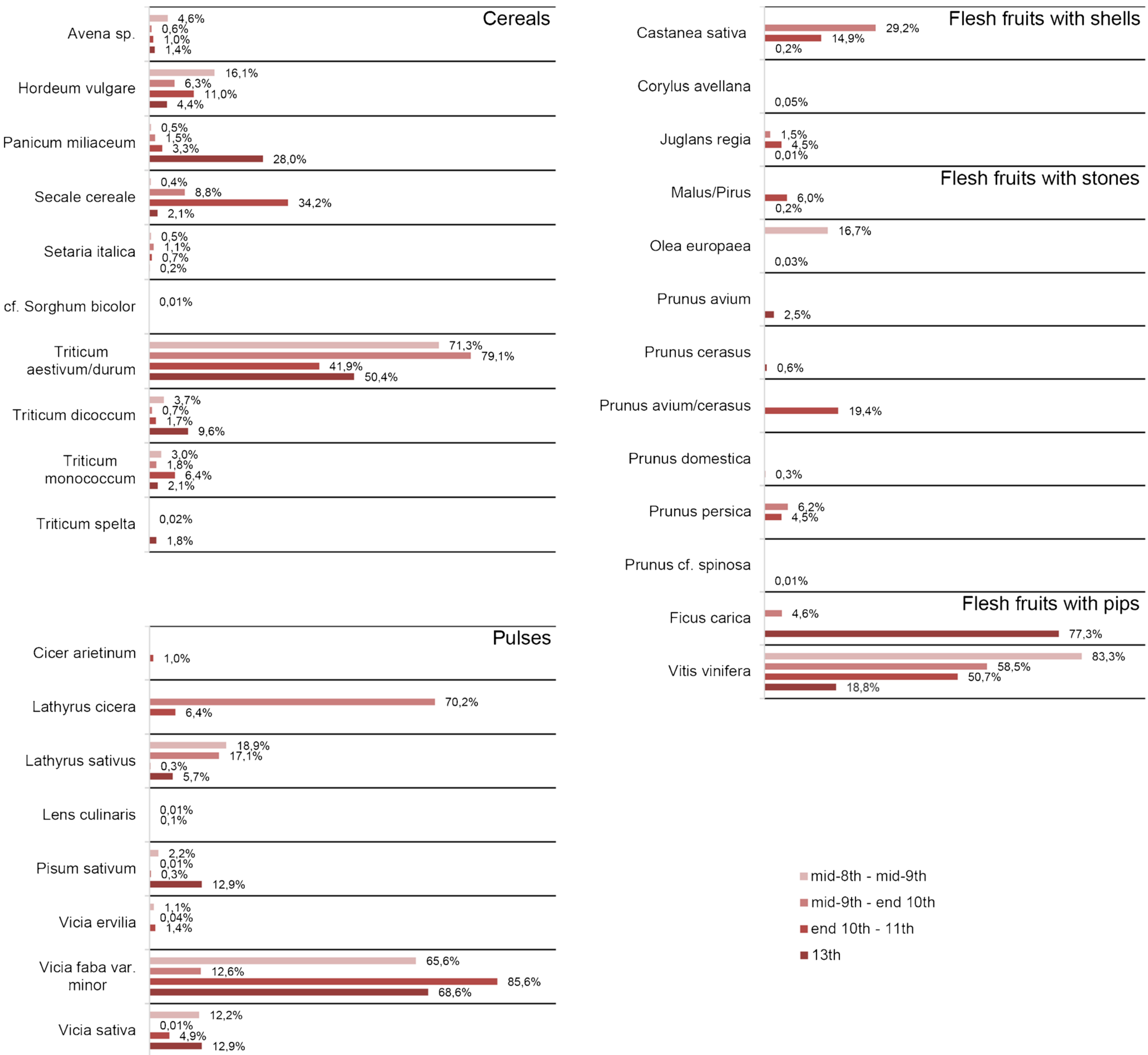

Fig. 2 Comparison of the percentages for the cereals, pulses, and fruits per period between the mid-eighth and thirteenth century AD

The material from Donoratico dates to the later ninth century AD and consists of ten samples (Table 3), including five *testi*, typical Medieval Tuscan cooking plates, and five pots. The samples from Siena are one cooking pot from the tenth century AD, recovered during the excavations carried out under the Cathedral (Table 3), and nine cooking vessels found during the restoration works of the Carmine Convent, dated to the fourteenth century AD (Table 3; Giorgi et al. 2010; Pecci 2009). Data obtained from the study of samples recovered in Grosseto (Valdambrini et al. 2006) are also taken into account (Table 3). These include three pots and one pan from the twelfth century AD; one small jug, one jug and one bowl dating to the thirteenth century AD and a bowl from the fourteenth century AD (Pecci 2005; Valdambrini et al. 2006). The materials from Piombino (thirteenth century AD) include 21 vessels, adding up to 32 samples. Of these, ten pots, three pot colanders, one pan, three small jug, one jug, all of them in coarse ware, and two bowls and one colander in fine ware have been tested in different parts to verify cooking practices (Pecci and Salvini 2007; Salvini et al. 2008). Thirty-eight samples, specifically 16 pots, 11 jugs, 3 *paioli* and 8 *testi*, were recovered from the Via de Castellani context in Florence (thirteenth century AD; Pecci 2015).

In the case of Piombino, we sampled the lime in which the ceramics were contained, whereas in the other cases we took samples of the soil of the stratigraphic unit in which the ceramics were recovered in order to control post-depositional contamination.

Table 3 Sites investigated by the residue analysis of ceramic vessels with the number of sampled ceramic types

Site	UTM X (Easting)	UTM Y (Northing)	Elevation	Type of settlement	Centuries AD	Sampled ceramic types	Number of samples
Florence	681,599	4,848,636	47	Urban quarter	13th	Pots	16
						Jugs	11
						Paioli	3
						Testi	8
Siena	688,869	4,798,736	353	Urban settlement	10th	Pots	1
	688,751	4,798,299	347	Convent	14th	Pots	7
						Pans	1
						Pan colanders	1
Donoratico	628,995	4,778,200	178	Rural settlement	later 9th	Pots	5
						Testi	5
Piombino	624,523	4,753,685	23	Convent	13th	Pots	10
						Pans	1
						Colanders	1
						Pot colanders	3
						Jugs	1
						Small jugs	3
						Bowls	2
Grosseto	672,837	4,736,719	21	Urban quarter	12th–14th	Pots	3
						Pans	1
						Bowls	2
						Jugs	1
						Small jugs	1

UTM zone is 32T; elevation is expressed in m a.s.l.

The samples were pulverized after mechanically cleaning the ceramic and extracted using the following methodology: (a) The total lipid extraction was carried out following the methodology proposed by Mottram et al. (1999), using 1 g of grounded sample. Five microlitres of a standard solution of octacosane (3 mg/ml) was added to the powder before the solvent extraction. (b) After the total lipid extraction, a hydrolysis on the solid residues was carried out following Giorgi et al. (2010). (c) For the identification of wine markers, the protocol for the extraction proposed by Pecci et al. (2013b) was carried out on 500 mg of sample. All the extracts were derivatized by adding BSTFA (50 μl) and heated at 70 °C for 1 h. From the resulting solution, 1 μl was used for the GC-MS analysis. GC-MS analyses were performed at the University of Siena using a gas chromatograph CP3800 (Varian, Walnut Crick, CA, USA). This was equipped with a 30-mD, 0.25-mm (i.d.), 0.25-μm-film thickness fused silica capillary column (Rtx-5MS, Restek Corporation, Bellefonte, PA, USA) and coupled to a Saturn 2000 mass spectrometer (Varian, Walnut Creek, CA, USA) operated in the EI mode (70 eV). The GC oven temperature was held at 50 °C for 1 min, and then it was raised at 5 °C/min up to 300 °C and held isothermally for 10 min. Helium (purity 99.995 %) flowing at 1 ml/min was used as the carrier gas. The mass range scanned was from m/z 40 to 650. In some cases, APCI-MS was also carried out on some samples following the method and analysis conditions published in Salvini et al. (2008).

Isotopic analyses of human and animal bones

Analyses of carbon and nitrogen stable isotopes involve 63 human bone samples (28 males, 19 females, 16 unclassified) and 26 animal specimens (10 swines, 11 ovines, 4 bovines and 1 fowl), for a total of 89 samples (Table 4). These came from rural contexts of three Medieval sites in Tuscany (Fig. 1): the castle of Monte di Croce (eleventh to twelfth centuries AD), the church of Pava (eleventh to twelfth centuries AD) and the church of Monti di Villa (twelfth to fourteenth centuries AD).

The study of isotopic markers of C and N for determination of paleonutrition of human remains is a well-tested technique that has been used for over 40 years (Ambrose 1993; Malainey 2011; Schoeninger 2010; Sealy 2001), although its application to the study of Italian Medieval society is relatively recent (Ricci et al. 2012; Torino et al. 2015). These isotopic

Table 4 Sites investigated with their respective historical periods, number of individuals (divided into males (M), females (F), and unclassified (n.c.)) and fauna analysed (distinct in different species)

Site	UTM X (Easting)	UTM Y (Northing)	Elevation	Type of settlement	Centuries	Number of human samples	Number of fauna samples
Monti di Villa	626,375	4,876,906	573	Rural settlement	12th–14th	23(8 M, 8 F, 7 n.c.)	8 (3 swines, 3 ovines, 2 bovines)
Monte di Croce	693,719	4,855,953	450	Rural settlement	11th–12th	18 (11 M, 4 F, 3 n.c.)	9 (3 swines, 3 ovines, 2 bovines, 1 fowl)
Pava	709,474	4,778,834	267	Rural settlement	11th–12th	22 (9 M, 7 F, 6 n.c.)	9 (4 swines, 5 ovines)

UTM zone is 32T; elevation is expressed in m a.s.l.

markers permit to examine the diet models in the last few years of life of the individuals, through isotopic analysis of collagen, highlighting the consumption of a particular type of food or the whole diet of the individual. The reconstruction of paleodiet is based on the analysis of the isotope ratios of carbon ($^{13}C/^{12}C$) and nitrogen ($^{15}N/^{14}N$) from collagen in human bone remains. Stable isotopes are reported as the measured difference in the isotopic composition of the sample (s) and an accepted standard (std), in terms of 'delta notation' (δ values) (Criss 1999):

$$\delta_s\ (‰) = \frac{Rs - Rstd}{Rstd} * 1000$$

where R is the isotope ratio between the heavy isotope and the light one of the same element. The standards used are internationally well defined: the Pe Dee Belemnite (PDB) for carbon and air for nitrogen (Criss 1999).

As several studies carried out in last decades have demonstrated (Ambrose 1993; Schoeninger 2010; Sealy 2001), a simple scheme for interpreting the measurements is the following. A diet based on aquatic feeding is characterized by ^{13}C and ^{15}N values higher than values from a diet typical of terrestrial ecosystems, where primary consumers have bone collagen $\delta^{13}C$ typically 4 ‰ higher than the plants they feed on and $\delta^{15}N$ between 6 and 12 ‰. In addition, the passage along the food chain (e.g. change from herbivores to omnivores, carnivores) leads to an increase in the $\delta^{15}N$ of 2 and of 1 ‰ in the $\delta^{13}C$ (Malainey 2011). To check local contamination, which causes systematic variation of the whole food chain, the site must be characterized by measuring faunal remains (e.g. sheep, cattle, etc.) for reference purposes since their role in the trophic levels is well known and constant (Malainey 2011; Schoeninger 2010).

The collagen extraction protocol has been applied on single bone remains (Longin 1971). A fragment of bone was sampled from each specimen. The bone surface was abraded to remove contaminants and pulverized. Each sample was then placed in polypropylene test tubes and demineralized in a sequence of acid attacks with hydrochloric acid (HCl 0.6 M) at ambient temperature (20–25 °C), interrupted by one alkali attack (NaOH 0.1 M). Several rinses with deionized water were carried out after each step, before oven-drying the samples. Finally, an extra treatment known as 'gelatinization' was performed and the extract freeze-dried at ca-80 °C (Lubritto et al. 2013).

For collagen quality tests, C and N fractions of collagen dry mass (C% and N%) were measured via an elemental analyzer (CN Flash EA 1112, Thermo Scientific). Samples were retained for isotope analyses when extracted collagen achieved a yield higher than 1 % and an atomic C/N ratio between 2.9 and 3.6 (De Niro 1985; Pate 1994; Van Klinken 1999). $\delta^{15}N$ and $\delta^{13}C$ were measured simultaneously in continuous flow mode, at the IRMS Laboratory of Seconda Università di Napoli, after collagen extraction and its quality assessment.

Results of isotopic measurements are presented in Fig. 3 and Table 5. In detail, $\delta^{13}C$ and $\delta^{15}N$ of single human (circle) and faunal (dash) samples are represented in Fig. 3, while in Table 5 the average value and standard deviation of carbon and nitrogen stable isotopes are reported for human individuals and for each species of faunal samples of the three sites.

Results and discussion

Cereals and pulses

In the hilltop villages between the mid-eighth and mid-ninth centuries AD, the main cultivated cereals (Fig. 2), with the most important role in the diet, are naked wheats (*Triticum aestivum/durum*, 71.3 %), integrated by barley (*Hordeum vulgare*, 16.1 %) and oat (*Avena* sp., 4.7 %). Pulses complete the diet; among them, horse bean (*Vicia faba* var. *minor*, 65.6 %), grass pea (*L. sativus*, 18.9 %) and common vetch (*Vicia sativa*, 12.2 %) are the more harvested crops (Fig. 2).

The strong presence of naked wheats, barley and horse bean suggests a farming system that maintains many of the characteristics of the Roman Age, since all the identified crops are dominant in Italy during the Roman period (Castelletti et al. 2001; Forni 2002). Interestingly, this is in agreement with the Early Medieval archaeobotanical data from northern Italy (Rottoli 2014). Therefore, the supposed Medieval decline of naked wheat cultivation (Andreolli 1981; Cortonesi 2002; Montanari 1979, 2002) is not observed in Tuscany and,

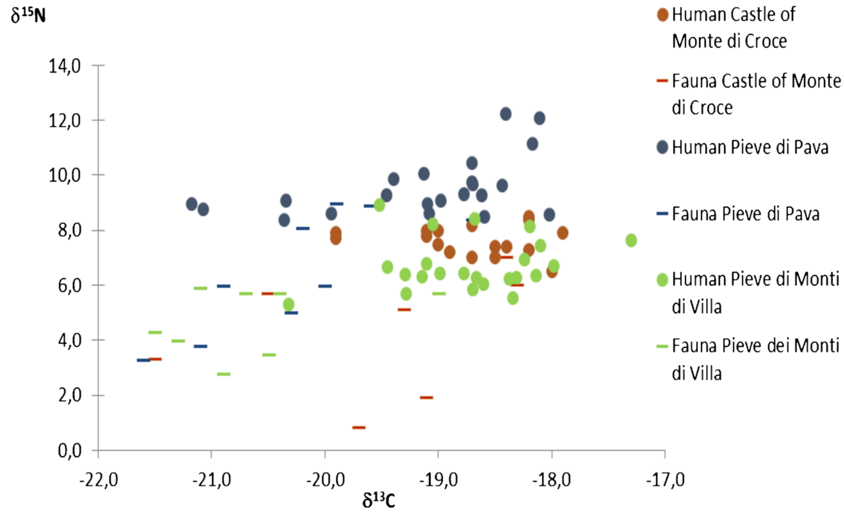

Fig. 3 δ^{15}N and δ^{13}C of single human and faunal samples, for each of the three sites

above all, the dietary staples of the Roman culture continue to characterize the diet even after the end of the Roman Age. In fact, the prominence as food crops of wheats, barley and horse bean is largely due to their large-kernelled grains, superior yield, high available carbohydrates and energy and high contents in digestible proteins (Baik and Ullrich 2008; Chavan et al. 1989; Crépon et al. 2010; Ofuya and Akhidue 2005).

Our data suggest that Early Medieval peasants have a good knowledge about both crop requirements and soil properties. Indeed, although soils are not very fertile closest to the sites, because of limiting factors, such as drainages, slopes and the presence of sand, clay and chalk, farming is mainly based on the cultivation of naked wheats.

On the other hand, the diet is completed both by several other large-kernelled cereals, like oat, emmer (*Triticum dicoccum*, 3.7 %) and einkorn (*Triticum monococcum*, 3 %), and by pulses, such as grass pea and common vetch (Fig. 2); interest in cereals with smaller grains, such as broomcorn millet (*Panicum miliaceum*, 0.5 %), is also locally attested in Miranduolo (Table 2, 6.6 % in the site). Comparing cereals

Table 5 Average values and standard deviations of δ^{15}N and δ^{13}C in the human and fauna samples

	Monte di Croce	Pava	Monti di Villa
δ^{13}C(‰) human	-18,6 ± 0,6	-19.2 ± 0.9	-18.7 ± 0.6
δ^{15}N (‰) human	7,6 ± 0,6	9.6 ± 0.6	6.8 ± 0.9
δ^{13}C(‰) swines	-21,1 ± 1,9	-19.6 ± 0.6	-20.0 ± 0.9
δ^{15}N(‰) swines	2,9 ± 0,9	8.6 ± 0.4	5.7 ± 0.1
δ^{13}C (‰) ovines	-19,8 ± 0,6	-20.8 ± 0.6	-21.8 ± 0.9
δ^{15}N(‰) ovines	3,9 ± 2,7	4.8 ± 1.2	4.7 ± 1.0
δ^{13}C (‰) bovines	-20,3 ± 2,8	–	-20.9 ± 0.6
δ^{15}N(‰) bovines	4,5 ± 2,2	–	3.8 ± 0.4
δ^{13}C (‰) fowl	-18,4 ± 0,1	–	–
δ^{15}N(‰) fowl	7,0 ± 0,2	–	–

with naked wheats, they are inferior for yield and they lack carbohydrates and gluten-like proteins; however, they have some dietary advantages, which contribute to excellent nutritional properties and high digestibility (Hidalgo and Brandolini 2014; Kalinova 2007; Zaharieva and Monneveux 2014). Grass pea seeds have chemical composition and nutritive value similar to horse bean (Enneking 2011). Overall, all these large-kernelled crops can be considered valued staple foods; furthermore, they are very rustic and characterized by hardiness and short life cycle, so they can be sown in winter and/or spring on poor soils and under limiting factors. These cereals and pulses allow to use all the available lands, to vary the crop production and, more generally, to limit the negative consequences of environmental adversities.

According to historical sources, the use of these so-called minor crops is a clear element of discontinuity with the Roman period (Andreolli 1981; Montanari 1979); however, rather than considering it a technological decline, it could be regarded as the peasants' response to the involution of the Medieval state, in order to ensure their own subsistence minimizing the risks (Wickham 2005). In fact, the archaeobotanical records do not suggest a retreat of agriculture in the High Middle Ages of Tuscany. On the contrary, they highlight a domestic and subsistence crop production, as indicated by the storage in silo pits for the needs of family units and the absence of buildings for crop storage in the villages (Bianchi and Grassi 2012).

The noticeable presence of einkorn, mainly recorded in the village of Miranduolo (Table 2, 26.7 % in the site) is very interesting. Einkorn, one of the first plants to be domesticated and cultivated (Zohary and Hopf 2004), has high resistance to pests and diseases and adaptation to poor soils and low inputs. Even if it is an ancient cereal, einkorn has some dietary advantages, contributing to the excellent nutritional properties of its flour (Hidalgo and Brandolini 2014; Rachoń et al. 2015; Zaharieva and Monneveux 2014). Nevertheless, unfavourable characteristics typical of a primitive cereal and the higheryielding and free-threshing naked wheats have caused the decline of this crop. During the Roman period, it is rarely found in the Italian peninsula (Castelletti et al. 2001). xEinkorn reappears in notable proportions only in the Early Medieval cereal assemblages of northern Italy (Rottoli 2014); in particular, between the sixth and tenth centuries AD, it has an important role in the Po Valley farming, characterizing the diet of the towns of Brescia and Parma (Bosi et al. 2011; Castelletti and Maspero 1988; Castiglioni et al. 1999). Like the Po Valley (Brogiolo 1993; Azzara 2004), the district of Miranduolo is characterized by Lombard culture. Thus, the cultivation of einkorn should be interpreted as evidence of a culturally specific production, connected to particular dietary habits and tastes.

In the manorial courts between the mid-ninth century and the end of the tenth century AD, naked wheats (79.2 %), barley (6.3 %) and horse bean (12.7 %) are still the main food crops (Fig. 2), suggesting a clear continuity with the agriculture developed in the villages at the beginning of the Middle Ages. Nevertheless, some differences with the previous farming system are detectable.

First, a new so-called minor cereal appears, rye (*Secale cereale*, 8.8 %), which is previously scarcely cultivated and represented in the archaeobotanical record (Fig. 2). This 'minor cereal' complemented the naked wheats and barley in the large-kernelled cereal assemblages. It is a winter cereal, very rustic, and it is even more productive than naked wheats and barley in poor sandy or loam soils and under frost. Moreover, rye has a chemical composition and nutritive value similar to naked wheats and similarly it is a free-threshing cereal (Chavan et al. 1989; Hansen et al. 2004).

In northern Italy, rye is scarcely and locally attested during the Late Roman Age in the western Po Valley (Blake et al. 1987; Castelletti 1975), Lugano Prealps (Castelletti and Castiglioni 1991) and the Ligurian Apennines (Castelletti 1976). According to historical sources (Montanari 1979) and archaeobotanical data (Castiglioni et al. 1999; Rottoli 2014), the cultivation of rye tends to increase in northern Italy during the Early Middle Age, maybe because it is more adaptable to climate conditions and it is appreciated by northern origin populations. Interestingly, our data well dated the beginning of the cultivation of rye in Tuscany to the second half of the ninth century AD. It is likely that this crop was selected because of its resistant, small requiring and productive qualities.

Similarly, among pulses (Fig. 2), the strong presence of grass pea (*L. cicera* 70.2 % and *L. sativus* 17.1 %) could indicate the will to cultivate the most difficult soils; in fact, this crop produces much more than other pulses in poorest and adverse lands. Moreover, grass pea seeds have high nutritional values very similar to horse bean (Enneking 2011). Therefore, grass pea cultivation could have been encouraged in order to integrate horse bean production and improve the yield of pulses.

The transition from villages to manorial courts coincides in Tuscany with the diffusion of the new Carolingian economic system, characterized by the control of the great landlords over the economies of the villages, including the possibility of surplus accumulation and the development of economic exchange with the creation of market places (Wickham 2005). The centralization of the best products is part of the manorial economy, and archaeological sources show that between the ninth and the tenth centuries AD, warehouses are built in several Tuscan settlements (Bianchi and Grassi 2012). The cultivation of both small requiring and productive large-kernelled crops is encouraged by the Carolingian aristocrats in order to achieve the highest production of any possible lands and to obtain the most profit from their estates.

Interestingly, the decreasing presence of einkorn (1.8 %) suggests a change in the role of this cereal, which becomes more marginal due to its unfavourable characteristics (Fig. 2). On the other hand, its important presence only in the crop record of Montarrenti (Table 2) shows a continuity in the choice of this cereal and the local persisting of a cultural heritage.

In the castles between the end of the tenth and the eleventh centuries AD (Fig. 2), rye has an important role (34.2 %), reaching a similar presence as the naked wheats (41.9 %). Therefore, only in this period does the cultivation of rye tend to increase in Tuscany, suggesting the farming system observed in northern Italy by the historical (Montanari 1979) and archaeobotanical sources (Rottoli 2014). On the other hand (Fig. 2), barley continues to have a minor presence (11 %), while horse bean is the main food pulse (85.6 %). Thus, the farming system is organized to keep stocks of large-kernelled grains with major nutritive value and economic importance.

In the central Middle Ages, when landlords are very powerful, exchange, productive specialization, and semi-industrial activity become very complex and affect also agriculture (Wickham 2005). In the estates of the castles, the farming system reaches the highest levels thanks to the experience obtained by the villages and manorial courts of the previous centuries. Therefore, the warehouses of the castles are now used to centralize the best crops to be sold in the market places.

The isotopic study carried out at the rural sites dated between the eleventh and the fourteenth centuries AD confirms a diet of vegetal origin. C4 cereals are particularly consumed, according to the intersite value for $\delta^{13}C$ of -18.8 ± 0.3 ‰. Analyzing the average results on the fauna diet (Table 5), the herbivorous (cattle, sheep) are mainly fed with C3 plants, indicating that the C4 component in human diet must, therefore, necessarily arise from the vegetal contribution in the diet. Only at Monte di Croce do domestic fowl have a similar diet to the humans and are clearly fed with C4 plants.

Our archaeobotanical data showed that C4 plants in the diet of Tuscan people were mainly broomcorn millet and, to a lesser degree, foxtail millet (*Setaria italica*) and sorghum (*Sorghum bicolor*). During the eleventh century AD, these crops have a secondary role in cereal assemblages of the castles, where C3 cereals, such as naked wheats, barley and rye, dominate. In fact, C4 cereals are considered low-quality dietary staple foods in comparison to C3 crop, as they are low in carbohydrate content, lacking in gluten-like proteins and not suitable for bread-making, but only for soups and gruels (Badi et al. 1990; Perten 1983). Since archaeobotanical data are referred mainly to the assemblages of the warehouses, where the best of the crop productions was stored by the landlords of the castles, probably C3 cereals are largely consumed and sold only by the upper class while peasants and low-status individuals have a limited access to higher-quality food.

According to historical sources, from this period the cash cropping begins to undermine the subsistence base of peasant communities (Wickham 2005). This trend continues mainly during the twelfth, thirteenth and fourteenth centuries AD, when the Late Medieval *Communi* (city-states) win against post-Carolingian landlords and insert the rural areas in the juridical, military, fiscal and economic system of the cities (Cherubini 1991; Fumagalli 1985). When cities started to control the countryside, they also pushed the production and import of wheats in order to increase bread-making (Montanari 1985; Piccinni 2002). Isotopic analysis of Monti di Villa confirms the farmers' food dependency on C4 plants between the twelfth and fourteeth centuries AD (Table 5 and Fig. 3). Despite the low quality of C4 crops, farmers could have developed processing methods to take advantage of their nutritional value, in particular of broomcorn millet. In fact, millet has higher protein quality compared to wheat, with a biological value on the level of pulse and wheat flour (Kalinova and Moudry 2006). Moreover, a leavened and fully satisfactory bread is possible to bake from a mixture of wheat and 20–30 % millet flour (Kalinova 2007).

Our archaeobotanical data, dated to the thirteenth century AD (Fig. 2), for the urban quarter in Florence confirm the predominant presence of naked wheats (50.4 %) in the diet, but here they are strongly complemented by broomcorn millet (28 %). Wheat bread is the symbol of the urban people, showing the superiority over the rural sites; however, the supplies of naked wheats are still unsufficient to cover the needs of the cities (Cortonesi 1997; Montanari 1985). In the thirteenth century AD, Florence cannot yet give up the minor cereals in the tradition of the difficult rural lands, such as broomcorn millet, emmer (9.6 %) and barley (4.4 %), which strongly contribute to satisfy the nutritional needs.

Livestock farming and the consumption of meat

Historical sources (Montanari 1979; Andreolli and Montanari 1985) and palaeobotanical data (Colombaroli et al. 2007; Di Pasquale et al. 2014) agree to show that the demographic crisis and the progressive depopulation at the end of the Roman Age have led to a strong spread of woodlands in the Early Medieval Tuscany. The marked reduction in cattle rearing and the corresponding increase in pig breeding recorded by archaeozoological studies can be connected to these changes of vegetation cover and simultaneously of the soil use (Salvadori 2011).

The results of the isotopic analysis on pigs are interesting. There are site-to-site differences in the isotopic values (Table 5): the specimens coming from Monte di Croce show lower δ^{15}N values (2.9 ± 0.9 ‰), compared to those coming from Monte di Villa (5.7 ± 0.1 ‰) and those coming from Pava site (8.6 ± 0.4 ‰). This variation can be explained with different practices in pig husbandry related to site-specific differences, i.e. probable swine farming in Pava site, where a more animal product intake is also evident in human diet. These results are coherent with previous studies focused on specific questions about certain peculiar foraging practices of medieval pigs (Hamilton and Thomas 2012; Hammond and O'Connor 2013; Müldner and Richards 2007; Sirignano et al. 2014).

The pig farming becomes therefore fundamental in the economy and in the diet of this period, decreasing and retreating in favour of the breeding of goats and sheep only from the thirteenth century AD. During the later centuries of the Middle Ages, the farming of these two species becomes instead very important for the diet, as its higher incidence in archaeozoological data suggests (Salvadori 2011).

The isotopic study confirms the importance of animal origin products in the diet of the rural sites between the eleventh and fourteenth centuries AD (Table 5 and Fig. 3). No differences were recorded between males (intersite value for δ^{15}N of 8.0 ± 1.2 ‰—no. of samples 28) and females (intersite value for δ^{15}N of 7.8 ± 1.3 ‰—no. of samples 19). It is also worth noting that, as it is expected, none of the Medieval rural samples in inner Tuscany shows either high values of δ^{13}C and δ^{15}N or a correlation between the values of δ^{13}C and δ^{15}N. This evidence points towards a low intake of marine proteins.

The study of the residues preserved in ceramic vessels confirms the consumption of animal products in order to supplement the diet. These are mostly consumed in the form of broths and soups but also roasted and possibly fried. In fact, residue analysis of ceramic vessels shows (Fig. 4) the presence of animal products (indicated by the presence of cholesterol) in almost all the vessels analysed, including both urban and rural sites from the ninth to the fourteenth centuries AD (Buonincontri et al. 2007; Giorgi et al. 2010; Pecci 2005, 2009; Pecci and Salvini 2007; Salvini et al. 2008; Valdambrini et al. 2006). This is true for different ceramic forms such as pots, pans and even coarse ware jugs and small jugs where the broths and soups could have been reheated. Only one coarse ware pot from the Carmine Convent in Siena and two small fine ware pots from Piombino, which do not show soot marks, do not show any residue, suggesting that they were used to contain water or solid materials (i.e. cereals). A further interesting point is that the analyses performed do not allow to identify drastic differences in time in the use of ceramic vessels.

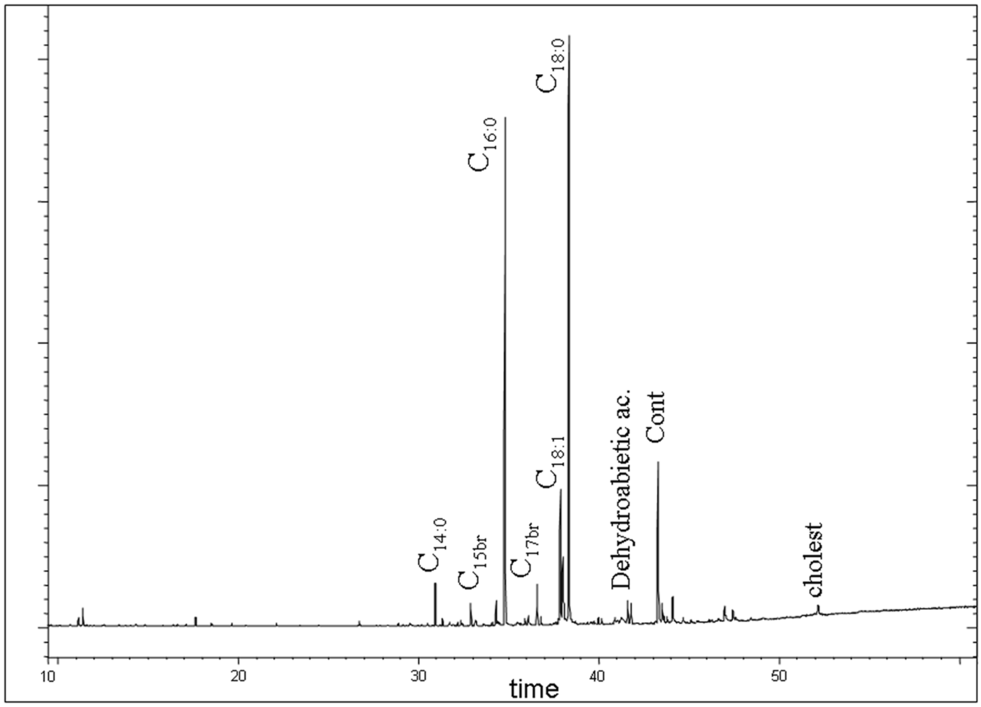

Fig. 4 Example of a chromatogram obtained with the GC-MS analysis of a cooking pot from Grosseto. It is possible to observe the presence of cholesterol, marker of animal origin products

Cooking plates (*testi*) are usually thought to have been used to cook bread (Pruno 2003). However, even in some of the samples from these ceramic forms, we found traces of animal products. These could be related to the cooking of meat and the addition of animal products to the bread to give flavour or to avoid food to stick on the plate surface. In addition, residues of animal products can be a result of the use of these vessels as tablewares, to display animal origin foodstuff. In general the results of the analyses indicate the presence of fats from rumiants. However, it is important to observe that, with the analyses performed, the chemical signature of rumiants covers the one of non rumiants that were eventually cooked. In the future, residue analysis of vessels should be complemented with isotopic analyses to better identify the origin of the animal products and with phytolith or starch analyses in order to verify if the containers were also employed to cook cereals.

Vegetables and other plant origin products

The residue analysis shows the presence of nonacosan, nosacosan-15one and nonacosan-15ol, in most of the vessels analysed. Although there is still some discussion on the markers of such products, they could be associated with the cooking of Brassicaceae (Chartres et al. 1993). Consumption of these vegetables is reported by the historical sources (Sordini 2004; Zazzeri 2003) and seems to be characteristic of Tuscan foodways. Cabbages—in particular black cabbages—are still typical of Tuscan cuisine nowadays. Actually, these residues have only been found in Tuscany, while they are not present in other Late Roman and Medieval contexts analysed by the author in Italy and Spain (Inserra et al. 2015; Pecci and Cau 2014).

Other plant origin products identified by the organic residue analysis are Pinaceae products (whose biomarkers are dehydroabietic, abietic and 7oxo-dehydroabietic acids and sometimes retene and methyldehydroabietate). They are present in almost all the vessels analysed, suggesting that these vessels were coated with an organic waterproofing agent, and indicating the presence of a technological characteristic typical of Medieval Tuscany (Pecci 2006). However, it is also possible that some of these products were used in the preparation of specific foodstuff, as a condiment or as a medicine (Sordini 2004). In three big pots from Piombino, the presence of a thick layer of Pinaceae pitch suggests that this product was used to waterproof the boats of the near port (Pecci and Salvini 2007).

Chestnut fruits, olive oil and wine

During the Early Middle Ages, the distribution and nature of activities across rural sites is probably the main responsible for the poor representation of fruits in the excavated assemblages (Fig. 2). Instead, fruits were better preserved in the waterlogged layers of the Late Medieval urban quarter of Florence, due to the rubbish feature of the archaeological contexts. As a whole, fruits with shells and stones are underrepresented, while fruits with pips, such as grape vine (*Vitis vinifera*) and fig (*Ficus carica*), are probably overestimated.

From the Early to the Late Middle Ages, fruits of cultivated plants prevail, hence the capable agricultural knowledges, hypothesized for crop production, can also be observed in fruit and nut growing. Remains of charred fruit come mainly from several contexts related to the warehouses of the manorial court and castles, suggesting that their consumption is probably reserved for the leading social class. Comparing organic residue analysis and archaeobotanical data, other considerations can be made in order to gain new insights onto the history of some of the most important arboreal landscapes, which still make Tuscany famous, such as those of chestnut woods, olive groves and vineyards.

Historical sources suggest that chestnut fruits (*Castanea sativa*) constituted the dominant food crop in the diet of the Apennine peasants of Tuscany, since Late Medieval times. Local economy was so much dependent on chestnut woods that the term 'chestnut culture' has been created to express the closely knit cultural relation of upland peoples with this tree species and their knowledge and expertise in managing the forest and guaranteeing their economic autonomy (Cherubini 1981).

Our recent review on archaeobotanical data of chestnut timber and fruits in the archaeological sites has showed that chestnut trees are present in Tuscany at least since the Late Roman Age and used for timber production and fuelwood until the mid-ninth century AD (Buonincontri et al. 2015). From the mid-ninth century AD, during the Carolingian system of the manorial courts, chestnut ceases to be used for timber and fuel production (Buonincontri et al. 2015), while chestnut fruits are picked and kept in the warehouses of the landlord (29.2 %; Fig. 2), thus suggesting the management of chestnut woods for fruit production. From the tenth century, chestnut was exploited in the estates of the castles for both timber (Buonincontri et al. 2015) and fruits (14.9 %; Fig. 2), suggesting the abundance of this resource in high-managed stands. These data indicate that chestnut cultivation for fruit spread in Tuscany at the same time as the spread of the Carolingian socioeconomic reform, which reorganized the land and agricultural production to obtain a production surplus and benefit from processed products, typical of the market economy. In the thirteenth century AD, chestnut fruits are traded and sold in the city of Florence (0.2 %; Fig. 2), constituting evidence of a landscape in expansion and dating the time during which chestnut becomes a food crop 'globally' (Cherubini 1981).

It is difficult to demonstrate the use of ceramic vessels for the cooking of chestnuts. However, a pan-colander from the archaeological site of the Carmine Convent in Siena, dated to the fourteenth century AD, shows soot marks both in the internal and external parts, and there is absence of residues, which is compatible with the roasting of chestnuts, as experiments have shown (Fig. 5; Pecci 2005). To buttress this interpretation, we found other references to the widespread use of similar vessels to roast chestnuts until few years ago in Spain and Portugal (thirteenth century AD). It is intriguing to observe that this ceramic vessel dated to the Late Middle Ages, which corresponds to the phase of expansion of the 'chestnut culture'.

According to palaeoenvironmental data, olive tree (*Olea europaea*) shows a very similar trend to that of chestnut and the presence of olive increased significantly from the Late Middle Ages onwards (eleventh and twelfth centuries AD) and in particular in the thirteenth century AD (Di Pasquale et al. 2014). Historical sources (Cortonesi 2005; Pinto 2002) demonstrated that olive tree cultivation before the tenth century AD was characteristic only of ecclesiastic and aristocratic contexts, while from the end of the fourteenth century AD, a major and definitive development of olive farming is recorded. The emergence of such landscapes is thus Late Medieval and may well be attributed to the set-up of the new economic organization with the establishment of the political system of the *Communi*, which led to the need to satisfy a rising demand for food and luxury products.

Fig. 5 *Left*: pot colanders used to roast chestnuts until 10 years ago in Spain (courtesy of J. Manuel Vázquez). *Right*: experiment of roasting chestnuts in a modern pot colander

The residue analysis study provides data in agreement with the archaeobotanical record, which shows the scarce presence of olive fruits until the Late Middle Ages (Fig. 2), and it indicates a late exploitation of olive oil in the different sites analysed. In fact, evidence of consumption of probably olive oil only comes from the Late Middle Age and only from specific contexts. This is the case of the Carmine Convent and the Santa Maria della Scala Hospital in Siena (Pecci and Grassi 2016).

Moreover, the presence of linoleic acid in several samples, together with β-sitosterol, suggests that an oil different from olive oil was possibly used in the cooking of food in the different sites during the whole period analysed.

Regarding grapevine, archaeobotanical data showed the presence of its fruits during the whole period investigated. As for residue analysis, although tartaric acid, the marker of grape, is present also in other fruits (i.e. tamarind, Barnard et al. 2011), for the area and period investigated we can consider that it is related to the consumption of wine or its derivatives, if associated with fermentation markers (i.e. succinic acid). Therefore, residue analysis shows the consumption of wine, mainly in the Late Medieval contexts (Piombino, Grosseto and Firenze), as a beverage and as a condiment. Wine traces were, in fact, identified in fine ware small jugs (Valdambrini et al. 2006) and in coarse ware jugs (such as those from Piombino), suggesting that it was used as a beverage, as well as in cooking pots (from Florence and Piombino), probably for flavouring the food. Finally, wine traces were detected in small fine ware pots, where it was probably used in the preparation of sauces (Pecci 2015). This confirms the widespread use of wine and its derivatives (that cannot be chemically differentiated from wine) in Late Medieval diet, as indicated by historical sources and recipes (Redon et al. 1994; Zazzeri 2003).

The carpological data indicate that the presence of grapevine in the Medieval agricultural landscape is very scarce compared to the anthracological data of chestnut and olive, suggesting the scant presence of grapevine farming in Tuscany at least until to the thirteenth century AD (Di Pasquale et al. 2014; Buonincontri et al. 2015). This is in agreement with the historical sources. During the Early Middle Age, grapevine is cultivated mainly in religious properties, for the role that wine plays in Christian worship, and in aristocratic landed properties, as a symbol of luxury and prestige (Pinto 2002). Indeed, the presence of grape pips in our coeval archaeobotanical data is related mostly to the storage areas of the manorial courts and castles under strict control of the landlord (Fig. 2). Only from the thirteenth century AD copious documentation on viticulture is present, suggesting a greater and more extensive cultivation of grapevine (Pinto 2002).

Conclusions

The history of food production and diet in Medieval Tuscany was known by historical sources. These sources underline the regression of the dietary staple foods in relation to the Roman ones, emphasizing the decline of use of wheat; the spread of a wide variety of lower-quality crops to avoid the consequences of poor harvests; the collecting of wild plants and fruits and the consumption of abundant animal meats. Our research, comparing archaeobotanical data, isotopic analyses and organic residue analyses of ceramic vessels, has broadened this view and allowed to investigate in more detail the food production and the diet between the mid-eighth and the fourteenth centuries AD with a close comparison with the socioeconomic events and the archaeological data.

Although the end of the Roman Empire caused the collapse of the manufacturing and agriculture systems, as well as of the settlement network, with the abandonment of wide cultivated lowland areas, the diet in the rural villages of the Early Middle Ages is qualitatively similar to that of Roman Age. This includes the cultivation of naked wheats, barley and horse bean, the best cultivable crops for nutritional value and yield. Naked wheats, the cereals for bread-making, remain clearly dominant throughout the period, supported mainly by horse bean, confirming the Tuscan peasants' quality and technological capacity in the whole Middle Ages.

However, since the beginning, this diet includes other cereals and pulses usually defined by historians as 'minor'. Compared with agronomic literature, these crops are minor only in terms of yield and aptitude for baking, rather than for nutritive quality: characterized by excellent nutritional properties, by high digestibility and for being rich in proteins, they supplement abundantly the diet. Furthermore, their hardiness allows to best exploit the most degraded and adverse areas, providing harvests. Therefore, oat, emmer, einkorn, rye and common millet can be suitable for gruels and soups, as well as for producing mixed wheat bread or only flat unleavened bread. They are dietary staple foods, always present throughout the Medieval Ages, but their ratio changes over time, either according to the dominant culture (einkorn) or because they are not useful (oat) or because they increase the crop production for the revived markets and trade (rye and grass pea).

Among minor cereals, C4 plants, in particular common millet, have a dominant role in the peasants' diet towards the Late Middle Ages, when the wheat production is strictly collected first by the landlords and then by the cities for their own needs. Common millet, with its high-quality protein and biological value, experienced in the rural areas, will be widely present in the diet of the cities, supporting the wheat bread to supply the urban populations.

According to historical and archaeozoological data, livestock farming plays a major role in the Medieval economy throughout the whole period studied. In particular, pig farming and the nutritional supplement of animal meat to the diet of rural and urban populations are well documented by our data since the ninth century AD of the Early Middle Ages. Therefore, cereals, pulse and meats can be probably considered the staple ingredients of the foods cooked in the ceramic vessels, mixed with vegetables. Interestingly, the dietary fish supply is very scarce in rural areas.

Finally, another issue our work was able to rise is that the Tuscan great tradition of olive oil, wine and chestnut fruit production starts in the Middle Ages, becoming part of the agro-forestry landscape until today. In particular, the chestnut woods for fruits have origin in the mid-ninth century AD when the Carolingian lords' desire to take profit from forest areas spreads. At the start, chestnut fruits are destined to the higher social classes. Wine and olive oil have a very scarce presence in the diet until at least the Late Middle Ages, and mainly in urban areas and in particular higher social classes, such as the religious ones. In fact, only between the twelfth and thirteenth centuries AD is the great expansion of olive groves and vineyards recorded, when cities and urban populations claim to have access to these luxury foods.

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References

Ambrose HS (1993) Isotopic analysis: methodological and interpretive considerations. In: Sandford MK (ed) Investigations of ancient human tissue: chemical analyses in anthropology. Gordon and Breach Scientific, New York, pp. 59–130

Andreolli B (1981) I prodotti alimentari nei contratti agrari toscani dell'Alto Medioevo. Archeol Mediev 8:117–126

Andreolli B, Montanari M (1985) L'azienda curtense in Italia. Proprietà della terra e lavoro contadino nei secoli VIII-XI. Clueb, Bologna

Azzara C (2004) Parma nell'Emilia longobarda. Reti Mediev Riv 5:1–11

Baccarini L (2007) L'analisi funzionale di un corredo ceramico da cucina altomedievale: il caso di studio di un edificio in legno del sito di Donoratico (Castagneto Carducci, LI). Dissertation, Università di Siena

Badi S, Pedersen B, Monowar L, Eggum BO (1990) The nutritive value of new and traditional sorghum and millet foods from Sudan. Plant Foods Hum Nutr 40:5–19. doi:10.1007/BF02193775

Baik BK, Ullrich SE (2008) Barley for food: characteristics, improvement, and renewed interest. J Cereal Sci 48:233–242. doi:10.1016/j.jcs.2008.02.002

Barnard H, Dooley AN, Areshian G, Gasparyan B, Faull KF (2011) Chemical evidence for wine production around 4000 BCE in the Late Chalcolithic Near Eastern highlands. J Archaeol Sci 38:977–984. doi:10.1016/j.jas.2010.11.012

Bianchi G, Grassi F (2012) Sistemi di stoccaggio nelle campagne italiane (secc. VII–XIII): l'evidenza archeologica dal caso di Rocca degli Alberti in Toscana. In: Vigil-Escalera Guirado A, Bianchi G, Quirós Castillo JA (eds) Horrea, barns and silos. Storage and incomes in Early Medieval Europe. Servicio editorial de la UPV/EHU, Bilbao, pp. 58–77

Blake H, Maccabruni C, Mannoni T, Setti M, Veniale F, Freestone I, King A, Nisbet R (1987) Dallo scavo a Villa Maria di Lomello (Pavia), 1984: la buca tardo-antica 203. Archeol Mediev 14:157–187

Bosi G, Bandini Mazzanti M, Florenzano A, N'siala Massamba I, Pederzoli A, Rinaldi R, Torri P, Mercuri AM (2011) Seeds/fruits, pollen and parasite remains as evidence of site function: piazza Garibaldi—Parma (N Italy) in Roman and Mediaeval times. J Archaeol Sci 38:1621–1633. doi:10.1016/j.jas.2011.02.027

Brogiolo GP (1993) Brescia altomedievale: urbanistica ed edilizia dal IV al IX secolo. Società Archeologica Padana, Mantova

Buonincontri MP (2009) L'archeobotanica in un contesto urbano medievale: il caso di Firenze. Dissertation, Università di Siena

Buonincontri MP, Di Falco G, Di Pasquale G (2013) Boschi e coltivi: la gestione delle risorse agroforestali. In: Grassi F (ed) L'insediamento medievale nelle Colline Metallifere (Toscana, Italia). Archaeopress, Il sito minerario di Rocchette Pannocchieschi dall'VIII al XIV secolo. Oxford, pp. 161–164

Buonincontri MP, Moser D, Allevato E, Basile B, Di Pasquale G (2014) Farming in a rural settlement in central Italy: cultural and environmental implications of crop production through the transition from Lombard to Frankish influence (8th–11th centuries A.D.). Veg Hist Archaeobotany 23:775–788. doi:10.1007/s00334-013-0429-8

Buonincontri MP, Pecci A, Corbino CA, Di Pasquale G, Donnini D, Mori Secci M, Pecci A, Pignatelli S, Salvin L, Terzani M (2007) Approccio integrato allo studio dell'alimentazione e dell'ambiente a Firenze nel XIII secolo: risultati preliminari. In: Cantini F, Cianferoni C, Francovich R, Scampoli E (eds) Firenze prima degli Uffizi. All'Insegna del Giglio, Firenze, pp. 662–682

Buonincontri MP, Saracino A, Di Pasquale G (2015) The transition of chestnut (*Castanea sativa* Miller) from timber to fruit tree: cultural and economic inferences in the Italian peninsula. The Holocene 25: 1111–1123. doi:10.1177/0959683615580198

Cantini, F (2003) Il Castello di Montarrenti. Lo scavo archeologico (1982–1987). Per la storia della formazione del villaggio medievale in Toscana (secc. VII–XV). All'Insegna del Giglio, Firenze

Castelletti L (1975) Segale (*Secale cereale* L.) subfossile a Lomello. Atti CeSDIR 6:55–71

Castelletti L (1976) Resti vegetali macroscopici da Refondou presso Savignone. Archeol Mediev 3:326–328

Castelletti L, Castiglioni E (1991) Resti vegetali. In: Brogiolo GP, Castelletti L (eds) Archeologia a Monte Barro I. Il grande edificio e le torri. Edizioni Stefanoni, Galbiate, pp. 169–203

Castelletti L, Castiglioni E, Rottoli M (2001) L'agricoltura dell'Italia settentrionale dal Neolitico al Medioevo. In: Failla O, Forni G (eds) Le piante coltivate e la loro storia. FrancoAngeli, Milano, pp. 63–156

Castelletti L, Maspero A (1988) Analisi di resti vegetali macroscopici. In: Panazza G, Brogiolo GP (eds) Ricerche su Brescia altomedioevale, vol 1. Lo scavo di via Alberto Mario. Ateneo di Brescia Accademia di Scienze Lettere ed Arti, Brescia, pp. 125–132

Castiglioni E, Cottini M, Rottoli M (1999) I resti botanici di Santa Giulia a Brescia. In: Brogiolo, GP (ed) Giulia di Brescia, gli scavi dal 1980 al 1992. Reperti preromani, romani e altomedievali. All'Insegna del Giglio, Firenze, pp 401–424

Chartres S, Evershed R, Goad LJ, Leyden A, Blinkhorn PW, Denham V (1993) Quantification and distribution of lipid in archaeological ceramics: implications for sampling potsherds for organic residue analysis and the classification of vessel use. Archaeom 35:211–223. doi:10.1111/j.1475-4754.1993.tb01036.x

Chavan JK, Kadam SS, Beuchat LR (1989) Nutritional improvement of cereals by fermentation. Crit Rev Food Sci Nutr 28:349–400. doi:10.1080/10408398909527507

Cherubini G (1981) La «civiltà» del castagno in Italia alla fine del Medioevo. Archeol Mediev 8:247–280

Cherubini G (1991) Le città italiane dell'età di Dante. Pacini Editore, Pisa

Colombaroli D, Marchetto A, Tinner W (2007) Long-term interactions between Mediterranean climate, vegetation and fire regime at Lago di Massaciuccoli (Tuscany, Italy). J Ecol 95: 755–770. doi:10.1111/j.1365-2745.2007.01240.x

Cortonesi A (1997) I cereali nell'Italia del tardo Medioevo. Note sugli aspetti qualitativi del consumo. In: Cavaciocchi S (ed) Alimentazione e nutrizione secc. XIII-XVIII. Le Monnier, Firenze, pp. 263–276

Cortonesi A (2002) Agricoltura e tecniche nell'Italia medievale. I cereali, la vite, l'olivo. In: Cortonesi A, Pasquali G, Piccinni G (eds) Uomini e campagne nell'Italia medievale. Roma-Bari, Laterza, pp. 190–270

Cortonesi A (2005) L'olivo nell'Italia medievale. Reti Mediev Riv 6:2–29. doi:10.6092/1593-2214/190

Crépon K, Marget P, Peyronnet C, Carrouée B, Arese P, Duc G (2010) Nutritional value of faba bean (Vicia faba L.) seeds for feed and food. Field Crops Res 115:329–339. doi:10.1016/j.fcr.2009.09.016

Criss RE (1999) Principles of stable isotope distribution. Oxford University Press, Oxford

De Niro MJ (1985) Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. Nat 317:806–809. doi:10.1038/317806a0

Di Pasquale G, Buonincontri MP, Allevato E, Saracino A (2014) Human-derived landscape changes on the northern Etruria coast (western Italy) between Roman times and the late Middle Ages. The Holocene 24:1491–1502. doi:10.1177/0959683614544063

Enneking D (2011) The nutritive value of grasspea (*Lathyrus sativus*) and allied species, their toxicity to animals and the role of malnutrition in neurolathyrism. Food Chem Toxicol 49:694–709. doi:10.1016/j.fct.2010.11.029

Evershed R (2008) Organic residues in archaeology: the archaeological biomarker revolution. Archaeometry 50(6):895–924. doi:10.1111/j.1475-4754.2008.00446.x

Forni G (2002) Colture, lavori, tecniche, rendimenti. In: Forni G, Marcone A (eds) Storia dell'agricoltura italiana. 1. L'Italia antica, vol 2. Età romana. Accademia dei Georgofili, Firenze, pp. 33–84

Francovich R, Hodges R (2003) Villa to village. Bristol Classical Press, London

Fumagalli V (1985) Città e campagna nell'Italia medievale. Patron, Bologna

Garnier N (2007) Analyse de résidus organiques conservés dans des amphores: un état de la question. In: Bonifay M, Tréglia JC (eds) Late Roman coarse wares, cooking wares and amphorae in the Mediterranean. Archaeology and archaeometry. LRCW3. BAR International series 16622. Archaeopress, Oxford, pp. 39–49

Giorgi G, Salvini L, Pecci A (2010) The meals in a Tuscan building yard during the Middle Age. Characterization of organic residues in ceramic potsherds. J Archaeol Sci 37:1453–1457. doi:10.1016/j.jas.2010.01.005

Hamilton J, Thomas R (2012) Pannage, pulses and pigs: isotopic and zooarchaeological evidence for changing pig management practices in later medieval England. Mediev Archaeol 56:234–259

Hammond C, O'Connor T (2013) Pig diet in medieval York: carbon and nitrogen stable isotopes. Archaeol Anthr Sci 5:123–127. doi:10.1007/s12520-013-0123-x

Hansen HB, Moller B, Andersen SB, Jorgensen JR, Hansen A (2004) Grain characteristics, chemical composition, and functional properties of rye (*Secale cereal* L.) as influenced by genotype and harvest year. J Agric Food Chem 52:2282–2291. doi:10.1021/jf0307191

Hidalgo A, Brandolini A (2014) Nutritional properties of einkorn wheat (*Triticum monococcum* L.). J Sci Food Agric 94:601–612. doi:10.1002/jsfa.6382

Inserra F, Pecci A, Cau MA, Roig Buixó J (2015) Organic residues analysis of Late Antique pottery from Plaça Major-Horts de Can Torras (Castellar del Vallés, Catalonia, Spain). Per Min 84:123–138. doi:10.2451/2015PM0008

Kalinová J (2007) Nutritionally important components of Proso millet (*Panicum miliaceum* L.). Food 1:91–100

Kalinova J, Moudry J (2006) Content and quality of protein in Proso millet (*Panicum miliaceum* L.) varieties. Plant Foods Hum Nutr 61:43–47. doi:10.1007/s11130-006-0013-9

Longin R (1971) New method of collagen extraction for radiocarbon dating. Nat 230:241–242

Lubritto C, Sirignano C, Ricci P, Passariello I, Quiros Castillo JA (2013) Radiocarbon chronology and paleo-diet studies on the medieval site of Zaballa (Spain): preliminary insights into the study of social archaeology of the site. Radiocarb 55:1222–1232. doi:10.2458/azu_js_rc.55.16365

Malainey ME (2011) A consumer's guide to archaeological science. Analytical techniques. Springer, New York

Montanari M (1979) L'alimentazione contadina nell'alto Medioevo. Liguori, Napoli

Montanari M (1985) Il cibo dei contadini: mutamenti economico-sociali e trasformazione del regime alimentare dei ceti rurali. In: Andreolli B, Fumagalli V, Montanari M (eds) Le campagne italiane prima e dopo il Mille. Una società in trasformazione. Clueb, Bologna, pp. 195–216

Montanari M (2002) Colture, lavori, tecniche, rendimenti. In: Pinto G, Poni C, Tucci U (eds) Storia dell'agricoltura italiana. 2. Il medioevo e l'età moderna. Accademia dei Georgofili, Firenze, pp. 59–81

Mottram HR, Dudd SN, Lawrence GJ, Stott AW, Evershed RP (1999) New chromatographic, mass spectrometric and stable isotope approaches to the classification of degraded animal fats preserved in archaeological pottery. J Chromatogr A 833:209–221. doi:10.1016/S0021-9673(98)01041-3

Müldner G, Richards M (2007) Diet and diversity at later medieval Fishergate: the isotopic evidence. Am J Phys Anthr 134:162–174. doi:10.1002/ajpa.20647

Nigra BT, Faull KF, Barnard H (2015) Analytical chemistry in archaeological research. Anal Chem 87(1):3–18. doi:10.1021/ac5029616

Ofuya Z, Akhidue V (2005) The role of pulses in human nutrition: a review. J Appl Sci Environ Management 9:99–104. doi:10.4314/jasem.v9i3.17361

Pate FD (1994) Bone chemistry and paleodiet. J Archaeol Method Th 1:161–209. doi:10.1007/BF02231415

Pecci A (2005) For the definition of the function of archaeological spaces and ceramics: an archaeometric project. Dissertation, Università di Siena

Pecci A (2006) Rivestimenti organici nelle ceramiche medievali: un accorgimento tecnologico "invisibile"? Archeol Mediev 33:517–523

Pecci A (2009) Analisi funzionali della ceramica e alimentazione. Archeol Mediev 36:21–42

Pecci A (2015) Alimentazione nella Firenze medievale: l'analisi dei residui organici nelle ceramiche. In: D'Aquino V, Guarducci G, Nencetti S, Valentini S (eds) Proceedings of the Workshop Archeologia a Firenze: città e territorio. Archaeopress Archaeology, Oxford, pp. 373–378

Pecci A, Cau MA (2014) Residue analysis of Late Roman cooking pots and amphorae from Sa Mesquida (Mallorca, Balearic Islands). In: Poulou-Papadimitriou N, Nodarou E, Kilikoglou V (eds) LRCW4 Late Roman coarse wares, cooking wares and amphorae in the Mediterranean. Archaeology and archaeometry. BAR International Series S2616, Oxford, pp. 833–841

Pecci A, Cau MA, Garnier N (2013a) Identifying wine and oil production: analysis of residues from Roman and Late Antique plastered vats. J Archaeol Sci 40:4491–4498. doi:10.1016/j.jas.2013.06.019

Pecci A, Giorgi G, Salvini L, Cau MA (2013b) Identifying wine markers in ceramics and plasters with gas chromatography-mass spectrometry. Exp Archaeol Mater J Archaeol Sci 40:109–115. doi:10.1016/j.jas.2012.05.001

Pecci A, Grassi F (2016) Preliminary study of food residues and cooking practices in the Medieval Hospital of Santa Maria della Scala in Siena (Central Italy). Munibe Antropol Arkeol 67. in press

Pecci A, Salvini L (2007) Analisi dei residui organici assorbiti nelle ceramiche non rivestite del riempimento della volta absidale. In: Berti G, Bianchi G (eds) La chiesa di S.Antimo sopra i Canali a Piombino. Ceramiche ed architetture per la lettura archeologica di un cantiere medievale. All'Insegna del Giglio, Firenze, pp. 327–345

Perten H (1983) Practical experience in processing and use of millet and sorghum in Senegal and Sudan. Cereal Foods World 28:680–683

Pescini V, Aniceti V (2014) Archeobotanica e zooarcheologia per la ristrutturazione della storia alimentare nel Medioevo: il caso della Rocca degli Alberti. In: Luongo A, Paperini M (eds) Medioevo in Formazione, Tra ricerca e divulgazione, vol 4. Livorno, Debatte, pp. 49–57

Piccinni G (2002) La campagna e le città (secoli XII-XV). In: Cortonesi A (ed) Uomini e campagne nell'Italia medievale. Laterza, Bari, pp. 123–190

Pinto G (2002) Campagne e paesaggi toscani del Medioevo. Nardini Editore, Firenze

Pruno E (2003) La diffusione dei testelli nell'alto-Tirreno tra XI-XIV sec. In: Fiorillo R, Peduto P (eds) III Congresso Nazionale di Archeologia Medievale. All'Insegna del Giglio. Firenze, pp 71–77

Rachoń L, Szumiło G, Brodowska M, Woźniak A (2015) Nutritional value and mineral composition of grain of selected wheat species depending on the intensity of a production technology. J Elem 20:705–715. doi:10.5601/jelem.2014.19.4.640

Redon O, Sabban F, Serventi S (1994) A tavola nel Medioevo con 150 ricette dalla Francia e dall'Italia. Laterza, Bari

Regert M (2011) Analytical strategies for discriminating archeological fatty substances from animal origin. Mass Spectrom Rev 30:177–220. doi:10.1002/mas.20271

Renfrew J (1973) Palaeoethnobotany. Methuen, London

Ricci P, Mongelli V, Vitiello A, Campana S, Sirignano C, Rubino M, Fornaciari G, Lubritto C (2012) The privileged burial of the Pava Pieve (Siena eighth century AD). Rapid Commun Mass Spectrom 26:2393–2398. doi:10.1002/rcm.6302

Rottoli M (2014) Reflections on Early Medieval resources in northern Italy: the archaeobotanical and archaeozoological data. Quat Int 346:20–27. doi:10.1016/j.quaint.2014.01.014

Ruas MP (2005) Aspects of early medieval farming from sites in Mediterranean France. Veg Hist Archaeobotany 14:400–415. doi:10.1007/s00334-005-0069-8

Sadori L, Susanna F (2005) Hints of economic change during the late Roman Empire period in central Italy: a study of charred plant remains from "La Fontanaccia", near Rome. Veg Hist Archaeobotany 14:386–393. doi:10.1007/s00334-005-0010-1

Salvadori F (2011) Zooarcheologia e controllo delle risorse economiche locali nel medioevo. Post-Class Archaeol 1:195–244

Salvini L, Pecci A, Giorgi G (2008) Cooking activities during the Middle Age: organic residues in ceramic vessels from the Sant'Antimo Church (Piombino-Central Italy). J Mass Spectrom 43:108–115. doi:10.1002/jms.1283

Schoeninger MJ (2010) Diet reconstruction and ecology using stable isotope ratios. In: Larsen CS (ed) A companion to biological anthropology. Wiley, New York, pp. 445–464

Sealy J (2001) Body tissue chemistry and Palaeodiet. In: Brothwell DR, Pollard AM (eds) Handbook of archaeological sciences. Wiley, Chichester, pp. 269–279

Sirignano C, Sologestoa IG, Ricci P, Garcia-Collado MI, Altieri S, Quiros Castillo JA, Lubritto C (2014) Animal husbandry during Early and High Middle Ages in the Basque Contry (Spain). Quat Int 346:138–148. doi:10.1016/j.quaint.2014.05.042

Sordini B (2004) Il cibo e la cura. In: Belli M, Grassi F, Sordini B (eds) La cucina di un ospedale del Trecento. Gli spazi, gli oggetti, il cibo nel Santa Maria della Scala di Siena. Pacini Editore, Pisa, pp. 11–65

Torino M, Boldsen JL, Tarp P, Lund Rasmussen K, Skytte L, Nielsen L, Schiavone S, Terrasi F, Passariello I, Ricci P, Lubritto C (2015) Convento di San Francesco a Folloni: the function of a Medieval Franciscan Friary seen through the burials. Herit Sci 3:1–22. doi:10.1186/s40494-015-0056-z

Valdambrini C, A, Salini L (2006) Ceramiche da mensa e da dispensa da alcuni siti della provincia di Grosseto: rapporto contenuto/contenitore. In: Atti del Convegno Internazionale della ceramica. La ceramica da fuoco e da dispensa nel basso medioevo e nella prima età moderna (secoli XI-XVI). All'insegna del Giglio, Firenze, pp. 120–128

Valenti M (2004) L'insediamento altomedievale nelle campagne toscane. Paesaggi, popolamento e villaggi tra VI e X secolo. All'Insegna del Giglio, Firenze

Van Klinken GJ (1999) Bone collagen quality indicators for palaeodietary and radiocarbon measurements. J Archaeol Sci 26:687–695. doi:10.1006/jasc.1998.0385

Ward-Perkins B (2005) The fall of Rome and the end of the civilization. Oxford University Press, New York

Wickham C (1988) The mountains and the City: the Tuscan Appennines in the Early Middle Ages. The Clarendon Press, Oxford

Wickham C (2005) Framing the early middle ages: Europe and the Mediterranean, 400–800. Oxford University Press, New York

Zaharieva M, Monneveux P (2014) Cultivated einkorn wheat (*Triticum monococcum* L. subsp. *monococcum*): the long life of a founder crop of agriculture. Genet Resour Crop Evol 61: 677–706. doi:10.1007/s10722-014-0084-7

Zazzeri R (2003) Ci desinò l'abate. Ospiti e cucina nel monastero di Santa Trinita. Firenze, 1360–1363. Società Editrice Fiorentina, Firenze

Zohary D, Hopf M (2004) Domestication of plants in the Old World, 3rd edn. Oxford University Press, Oxford