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Title: The role of sheep husbandry during the Arab Agricultural Revolution in medieval Sicily (7th-14th c. AD)

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Abstract

Sheep, and to a lesser extent goat, pastoralism was a central component of the economy of medieval Sicily. Unlike the Byzantine period (6th- early 9th c.AD), when sheep/goat were mainly raised for their wool, husbandry strategies were~~are~~ much more generalised during the Arab occupation (9th-11th c. AD). In this latter period, caprines were equally exploited for meat, dairy products and wool. Biometrical analyses indicate an increase in sheep size in the Arab period, which is probably a consequence of an interest in maximising outputs. This phenomenon can be interpreted as a component of the broader changes associated with the so-called Arab Agricultural Revolution. In the Norman/Aragonese period (11th- late 13th~~h-14th~~ c. AD), a further improvement in sheep size indicates a continuity of the animal husbandry strategies initiated by the Arabs. In this period, sheep/goat culling profiles~~ now~~ suggest the existence of a more specialised economy focused on meat and, to a lesser extent, wool production.

Keywords: zooarchaeology, animal husbandry, biometry, medieval, Arab Agricultural Revolution, Sicily, southern Europe.

1. Introduction

'The green island of Trinacria
where the flock of the sun graze'
Homer, Odyssey IX

In the period spanning from the ca. 8th to the 13th century AD, the Mediterranean basin saw a radical transformation in agricultural practices known as the Arab Agricultural Revolution (Watson 1974; Garcìa Maceira 1876). The production systems established by the Arabs enabled the spread of new agricultural techniques and plants throughout the Arab world, including Sicily (Watson 1983). Although the use of the term 'revolution' is debatable (Squatriti 2014; Decker 2009; Butzer et al. 1985; Johns 1985), archaeological evidence has clearly attested that the arrival of the Arabs to Sicily (AD 827) substantially reshaped the agricultural landscape of the island. New techniques of irrigation, as well as plant species and varieties were introduced and adopted by local communities (Todaro et al. 2020; Molinari 2010). This is~~ the~~ demonstrated archaeologically by the finding of introduced aromatic herbs and vegetables, such as the aubergine remains found in Arab contexts at Mazara del Vallo in southwestern Sicily (Fiorentino et al. 2022~~in press~~; Primavera 2018).

However, if on the one hand the above-mentioned agricultural innovations are rather well-explored in archaeological and historical research, ~~(Fuks et al. 2020; Civantos 2011), ~~on the other, new ways of animal exploitation and potential introductions of animal breeds/species have barely been considered. Most scientific research still focuses on the 'green' side of the Arab Agricultural Revolution in Sicily - e.g., studies of new agricultural mechanisms and the introduction and diffusion of new plant varieties (Todaro et al. 2020; Fuks et al. 2020; Ros et al. 2016; Civantos 2011; Samuel 2001). ~~.~~Until recently, very little was known about the potential impact of such revolution on animal husbandry. Like the newly imported agricultural techniques and plants, different animal exploitation strategies and breeds could have been introduced to Sicily. Recent zooarchaeological analyses have demonstrated that the Arabs' arrival on the island influenced the dietary habits of the local population, and in particular that of urban communities where the religious taboo on pork consumption was more strictly followed than at contemporary rural sites (Aniceti and Albarella 2022). It is reasonable to think that, in addition to pig, the relationship with and use of other domesticates could have also been influenced by the Arabs. This is especially likely for sheep, as this species dominated the Sicilian livestock economy in the Arab period (Aniceti and Albarella 2022; Aniceti 2019).

In this study~~paper~~, for the first time, changes to sheep/goat husbandry practices and size in the Arab period are presented and interpreted as potential zooarchaeological evidence of the effects of the Arab Agricultural Revolution onto animal husbandry. This study~~e paper~~ will also discuss how such practices of animal management initiated by the Arabs were adopted and adapted in the Normans/Aragonese period. Published zooarchaeological data from Byzantine and Norman/Aragonese Sicily, as well as from other regions conquered by the Arabs (i.e., Al-Andalus, North Africa), will be used here as terms of comparison, facilitating the interpretation and contextualisation of the zooarchaeological evidence from Arab Sicily.

2. Sites and materials

The core dataset used for this paper relies on the study of sheep and goat remains collected from eight archaeological sites (urban and rural) located in various parts of Sicily (Fig.1) and dated between the Byzantine-Arab and Arab-Norman/Aragonese transitions (7^{th}-14^{th} c. AD). All sites had at least an Arab and/or a Norman/Aragonese phase. The only exception is Rocchicella, where two distinctive Byzantine phases occur but there is no later occupation (Table 1; Aniceti and Albarella 2022; Aniceti 2019).

Different taphonomic processes affected the animal bone assemblages. Of these, particularly important is the effect of recovery bias. Most bones were exclusively hand-collected during rescue excavations, and this is likely to have resulted in a bias in the taxonomic and anatomical representations. Small vertebrate species and smaller anatomical elements are likely to be underrepresented (Aniceti 2019). Although bone surface preservation was overall good, some remains were badly preserved; this was likely due to the combination of mechanical disturbance and chemical erosion. However, the underrepresentation of smaller anatomical elements (e.g. phalanges, carpals) does not impact on the results discussed in this study.

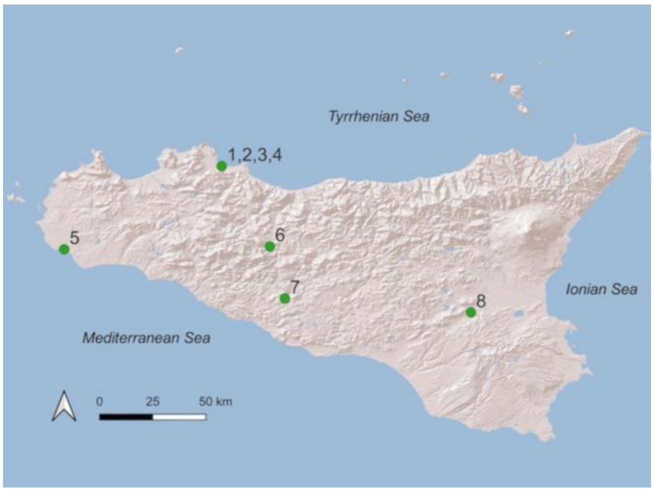


Fig.1 Location of the archaeological sites in Sicily whence the faunal assemblages analysed in this study were recovered. 1: Corso dei Mille; 2: Sant'Antonino; 3: the Norman Palace; 4: Castello San Pietro (Palermo); 5: Mazara del Vallo (Province of Trapani); 6: Casale San Pietro (Castronovo di Sicilia, Province of Palermo); 7: Colmitella (Province of Agrigento); 8: Rocchicella (Province of Catania).

sites	province	chronology	settlement type	reference(s)
1. Corso dei Mille	Palermo	10th-11th c. AD	urban	Battaglia et al. 2016
		12th-13th c. AD		Vassallo et al. 2016
2. Sant'Antonino	Palermo	late 9th-11th c. AD	urban	Aleo Nero 2017
3. The Norman Palace	Palermo	early 12th c. AD	urban	Vassallo et al. 2018
4. Castello San Pietro	Palermo	9th c. AD	urban	Arcifa and Bagnera 2014
				Arcifa and Lesnes 1997
				Di Stefano et al. 1989
5. Mazara del Vallo	Trapani	2nd ½ 10th – 2nd ½ 11th c. AD	urban	Molinari and Meo in press.
		2nd ½ 12th-late 13th c. AD		Molinari and Cassai 2006
				Cassai 2003
6. Casale San Pietro	Palermo	8th-9th c. AD	rural	Carver et al. 2019
				Carver et al. 2018
				Carver et al. 2017
7. Colmitella	Agrigento	7th/8th-9th c. AD	rural	Rizzo et al. 2015
		9th-11th c. AD		Rizzo et al. 2014
				Rizzo et al. 2012
				Rizzo and Romano 2012
8. Rocchicella	Catania	6th-7th c. AD	rural	Arcifa 2016
		9th c. AD		Maniscalco 2008

site	*province*	*chronology*	*period*	*settlement type*	*reference(s)*

1. Corso dei Mille	Palermo	10th-11th c. AD 12th-13th c. AD;	Arab period Norman/Aragonese period	urban	Battaglia et al. 2016 Vassallo et al. 2016
2. Sant'Antonino	Palermo	late 9th-11th c. AD	Arab period	urban	Aleo Nero 2017
3. The Norman Palace	Palermo	early 12th c. AD	Norman period	urban	Vassallo et al. 2018
4. Castello San Pietro	Palermo	9th c. AD	Arab period	urban	Arcifa and Bagnera 2014 Arcifa and Lesnes 1997 Di Stefano et al. 1989
5. Mazara del Vallo	Trapani	2nd ½ 10th - 2nd ½ 11th c. AD 2nd ½ 12th-late 13th c. AD	Arab period Norman/Aragonese period	urban	Molinari and Meo in press. Molinari and Cassai 2006 Cassai 2003
6. Casale San Pietro	Palermo	8th-9th c. AD	Arab period	rural	Carver et al. 2019 Carver et al. 2018 Carver et al. 2017
7. Colmitella	Agrigento	7th/8th-9th c. AD 9th-11th c. AD	Arab period Byzantine period	rural	Rizzo et al. 2015 Rizzo et al. 2014 Rizzo et al. 2012 Rizzo and Romano 2012
8. Rocchicella	Catania	6th-7th c. AD 9th c. AD	Byzantine period (1) Byzantine period (2)	rural	Arcifa 2016 Maniscalco 2008

Table 1 Essential information on the archaeological sites whence the faunal assemblages analysed in this study were recovered.

3. Methodology

3.1 Taxonomic identification

The identification of animal remains was helped by consultation of the animal bone atlases by Schmid (1972) and Barone (1976). The recording followed the Diagnostic Zone Method and applied a 50% integrity threshold (Albarella and Davis 1994), which allowed to mitigate the problem of interdependence of remains (Grayson 1984; Lyman 2008). The distinction between sheep (*Ovis aries*) and goat (*Capra hircus*) was attempted on a defined set of anatomical elements (Table 2), and was based on Boessneck (1969), Kratochvil (1969) and Zeder and Lapham (2010) for post-cranial bones and Payne (1985), Halstead et al. (2002) and Zeder and Pilaar (2010) for mandibular premolars. Other elements, unfused bones and any sheep/goat fragments for which a reliable species-level attribution was not feasible were directly assigned to the sub-family Caprinae. Salvagno and Albarella (2017) was used to allow an estimation of the proportion of sheep and goat remains based on biometrical analyses.

sheep/goat distinction - anatomical element~~s~~	
horncore	distal metacarpal
posterior cranium	distal tibia
mandible*	astragalus
loose teeth: dP_3, dP_4, P_3, P_4	calcaneum
proximal radius	distal metatarsal
distal humerus	-

Table 2 Anatomical elements on which separation between sheep and goat was attempted. * when at least one of these teeth was present: dP_3, dP_4, P_3, P_4.

3.2 Ageing

In this study, the age-at-death of sheep/goat has been estimated using two methods: the epiphyseal fusion status of postcranial bones and the eruption and wear patterns of mandibular teeth. ~~methods~~Epiphyseal fusion is used in this study~~article~~ as a primary source of ageing information, as a limited number of sheep/goat recordable mandibles were present in most of the analysed faunal assemblages. However, where possible, comparisons between the two ageing methods were made. To reconstruct mortality profiles, post-cranial bone fusion data were grouped into three age stages according to Silver (1969). Sheep/goat tooth eruption and wear stages were recorded following

Ewbank et al. (1964) and Payne (1973;1987) respectively. Sheep/goat m~~M~~andibles were attributed to age stages following Payne's method (1973) ~~only~~ when at least two teeth with recordable eruption/wear were present.

3.3 Biometry

Biometrical analyses are used in this paper to explore chronological and inter/intra-site variations in sheep/goat size. Measurements from sheep/goat post-cranial bones were taken according to von den Driesch (1976), Davis (1996), and Salvagno and Albarella (2017). The biometrical analyses presented in this paper focus on post-cranial measurements, as insufficient biometrical values were taken on teeth.

Morphological observations and biometrical analyses of sheep/goat post-cranial bones indicate that most of them, if not all, belonged to sheep; goat was present but in very small numbers (Aniceti and Albarella 2022; Aniceti 2019). Post-cranial bones assigned to sheep were included in biometrical analyses, while those belonging to goat were excluded.~~ from biometrical analyses, while those generically assigned to the sub-family Caprinae were included, as mostly deriving from sheep~~

Measurements were selected from a defined set of diagnostic zones, which tend to preserve better in the archaeological record and whose state of maturation (epiphyseal fusion stage) can be assessed. Sheep/goat fully fused~~ and fusing~~ bones ~~have been included~~were included in the biometrical analysis, while fusing and unfused ones were not. The analysis of absolute measurements from individual elements is usually preferred, as this allows for a greater control of factors affecting variation (e.g., ageing, sex, external stimuli; Payne and Bull 1988; Albarella 2002). However, in most cases, the sample size of measurements from individual elements was small, and measurements from the same anatomical element were not available for all sites.

Therefore, to increase the sample size and allow direct comparison between site and periods, measurements from different bones were merged by using a scaling index technique calculated through log ratios (Simpson et al. 1960; Meadow 1999; Albarella 2002). Such a technique consists of ~~in~~ calculating the decimal logarithm of the ratio between the archaeological value and a standard value (Meadow 1999). The standard employed in this study consists of the mean of measurements of sheep/goat bones from a sample of unimproved Shetland ewes as reported in Davis (1996). The use of scaling index techniques, however, presents some limitations, i.e., different measurements from different anatomical elements can be affected to varying extents by age, sex, environmental changes, and the introduction of new genotypes (Payne and Bull 1988). In order to minimise such effects, some precautions were taken. The smallest breadth of the diaphysis of long bones (SD) was excluded, since it tends to be heavily age-related. In addition, measurements lying on different axes should be analysed separately, as these can react differently to size change; in this study, to avoid an excessive reduction of the sample size, width and depth measurements had to be combined but length measurements were excluded. The HTC (vertical diameter of the trochlea at its central constriction) of the humerus is not easy to assign to a dimensional axis; here, it has been considered as a robustness indicator and, therefore, it has been included in the widths/depths group (Table 3).

The statistical significance of biometrical differences between the various groups of data was assessed by running Student's *t*-tests. Such a test is commonly used when measurements are normally distributed (as is the case of most groups of measurements analysed in this study~~paper~~); however, being a *robust* test, it is only marginally affected by variance (Simpson et al. 1960), and therefore can also be used when data are less than fully normally distributed. For these tests, statistical significance was tested at the 95% confidence level – $p < 0.05$ (see *Supplementary material*).

sheep/goat post-cranial elements	*measurements*	
	width	*depth*
humerus	BT, HTC	-
tibia	Bd	Dd
astragalus	Bd	Dl
calcaneum		GD
metacarpus	BFd, WCM, WCL	DEM, DVM, DIM, DIL, DVL, DEL
metatarsus	BFd, WCM, WCL	DEM, DVM, DIM, DIL, DVL, DEL

Table 3 Set of measurements used in biometrical analyses, taken after von den Driesch (1976) and Davis (1996).

4. Results

The taxonomic frequency of the main domesticates (cattle, caprines, and pig) has shown that caprines (mostly represented by sheep) were the most common species in most of the analysed sites and periods (Aniceti and Albarella 2022; Tables a, b in *Supplementary materials*).

In this section, sheep/goat ageing profiles and biometrical analyses on post-cranial elements are presented and compared between different sites and chronological periods.

4.1 Sheep/goat ageing profiles

The Byzantine period

Culling profiles of sheep/goat at rural Colmitella and Rocchicella show similar patterns, although some differences can be also detected (Fig. 2). At both sites, early culling events (early fusing stage), representing animals culled before their first-second year of age (lambs) are rare. At Colmitella, ca. 20% of sheep/goat were ~~are~~ culled by their second-third year of age (middle fusing stage) (Fig. 2a); fewer animals were~~are~~ slaughtered at this stage at Rocchicella (Fig. 2b-c). At Colmitella, most individuals (80%) survived into late adulthood (late fusing stage; ≥3-4 years of age), while at Rocchicella a slightly larger number of sheep and goats were culled before this age stage. Mandibular wear stages were estimated for 23 mandibles at Colmitella; the resulting kill-off pattern validate the results of the epiphyseal fusion analysis (Fig. 2d).

In sum, in the Byzantine period at Colmitella and Rocchicella mature sheep/goat were largely kept until later adulthood, being mainly exploited for their wool and breeding purposes, with fewer individuals culled as subadults for their meat. The very low incidence of lambs at both sites could suggest that the husbandry strategy was not focused on dairy products.~~;~~ H~~h~~owever, it is also possible that taphonomic processes (i.e., fragmentation, soil composition, pH level) compromised the survival of the most fragile and porous bones belonging to very young individuals, ~~of the more fragile bones of very young individuals,~~ which we would expect to find as part of a dairy economy. Post-depositional processes might have also affected the overall low incidence of perinatal bones, which indicate on-site breeding.

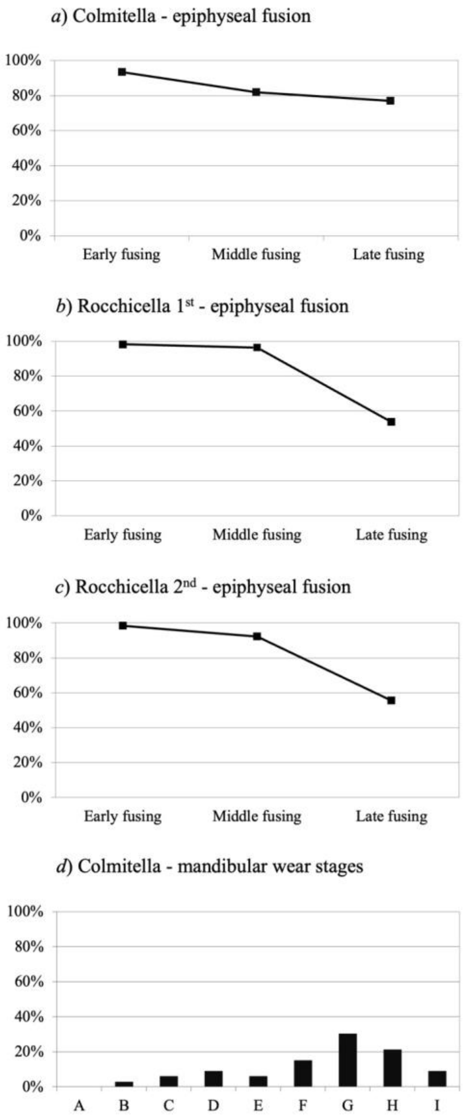


Fig.2 ~~Byzantine period – rural sites.~~ Percentage of fused sheep/goat bones within each fusion stage (Silver 1969) at Byzantine rural sites; early fusing stage: 12-24 months; middle fusing stage: 24-36 months; late fusing stage: 36-48 months - a: Colmitella (n:57;59;10); b: Rocchicella 1st phase (n:54;52;7); c: Rocchicella 2nd phase (n:64;83;5). Frequency of sheep/goat mandibular wear stages (Payne 1973) at Byzantine rural sites - d: Colmitella (n:23); A: 0-2 months, B: 2-6 months, C: 6-12 months, D: 1-2 years, E: 2-3 years, F: 3-4 years, G: 4-6 years, H: 6-8 years, I: 8-10 years.

The Arab period

At Arab urban sites, ca. 20% of sheep/goat were culled before reaching their 1st-2nd year of age (early fusing stage), although slight variations between sites do exist (Fig. 3a-d). In comparison to the Byzantine period, a higher number of individuals were slaughtered by their second-third year of age (middle fusing stage); ca. 20%-25% of the animals were culled before reaching their third-fourth year of age (late fusing stage; the only exception is Sant'Antonino), and ca. 35%-40% of individuals survived into adulthood.

In sum, the culling pattern from the Arab period at urban sites suggests a rather generalised economy where sheep/goat were exploited for meat as well as dairy products and wool production. Despite the overall low number of recovered sheep/goat mandibles at all sites, the kill-off patterns reconstructed from mandibular wear stages seem to corroborate the results from the epiphyseal fusion (Fig. 4a-d). At Sant'Antonino there seem to be two groups of animals, with the most numerous kept for meat and the smaller for secondary products (Fig. 4b).

The sheep/goat culling profile at the rural site of Arab Casale San Pietro entirely recalls those at urban sites, suggesting a quite generalised husbandry strategy with no focus on specific age groups (Fig. 5a). At Arab Colmitella, a larger number of individuals (ca. 20%) were culled before reaching their third-fourth year of age (late fusing stage) in comparison to the earlier Byzantine period, with another ca. 20% culled before the second-third year of age (middle fusing stage). Like in the previous phase, in the Arab period the majority of individuals (ca. 60%) survived into later adulthood (≥3-4 years of age). Early culling events (lambs) are rarer; their almost ~~virtual~~ complete absence could be a consequence of taphonomic processes, which could have detrimentally affected the survival of the more fragile bones of very young individuals (Fig. 5b).

At Casale San Pietro, the dental evidence suggests a higher incidence of culls in the first year than indicated by the bone fusion (i.e., stage C); such discrepancy may be the consequence of taphonomic processes, as the porous bones of very young individuals would preserve less well than their teeth (Fig. 5d~~b~~). The kill-off pattern reconstructed from sheep/goat mandibular wear stages at Arab Colmitella supports the result obtained from the epiphyseal fusion analysis (Fig. 5c). Overall, sheep/goat husbandry seems less specialised than in the previous phase. A higher number of animals were culled for their meat once they reached their optimum weight than in the previous period.

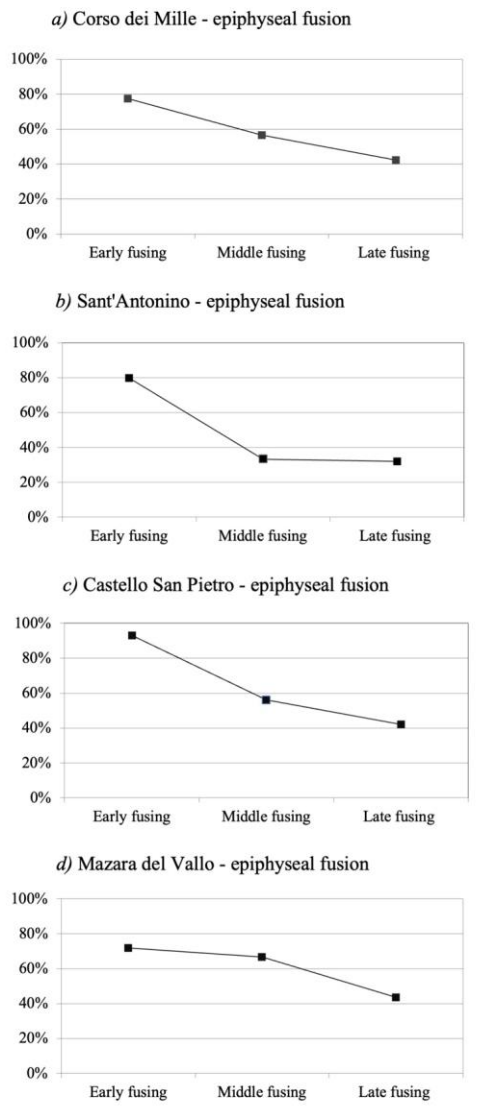


Fig.3 ~~Arab period – urban sites.~~ Percentage of fused sheep/goat bones within each fusion stage (Silver 1969) at Arab urban sites; early fusing stage: 12-24 months; middle fusing stage: 24-36 months; late fusing stage: 36-48 months - a: Corso dei Mille (n:48;17;11); b: Sant'Antonino (n:63;13;23); c: Castello San Pietro (n:69;45;23); d: Mazara del Vallo (n: 135;60;69).

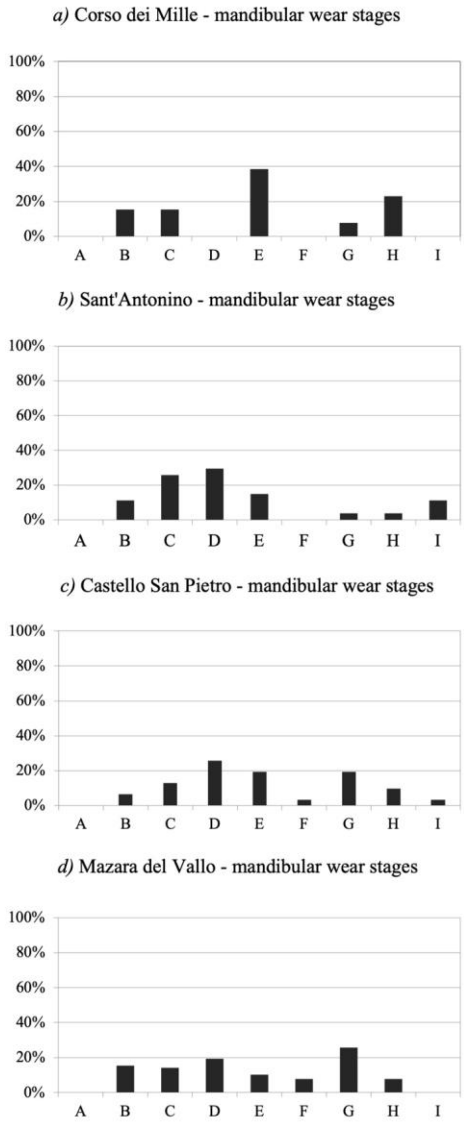


Fig.4 ~~Arab period - urban sites.~~ Frequency of sheep/goat mandibular wear stages (Payne 1973) at Arab urban sites - a: Corso dei Mille (13); b: Sant'Antonino (27); c: Castello San Pietro (31); d: Mazara del Vallo (58). A: 0-2 months, B: 2-6 months, C: 6-12 months, D: 1-2 years, E: 2-3 years, F: 3-4 years, G: 4-6 years, H: 6-8 years, I: 8-10 years.

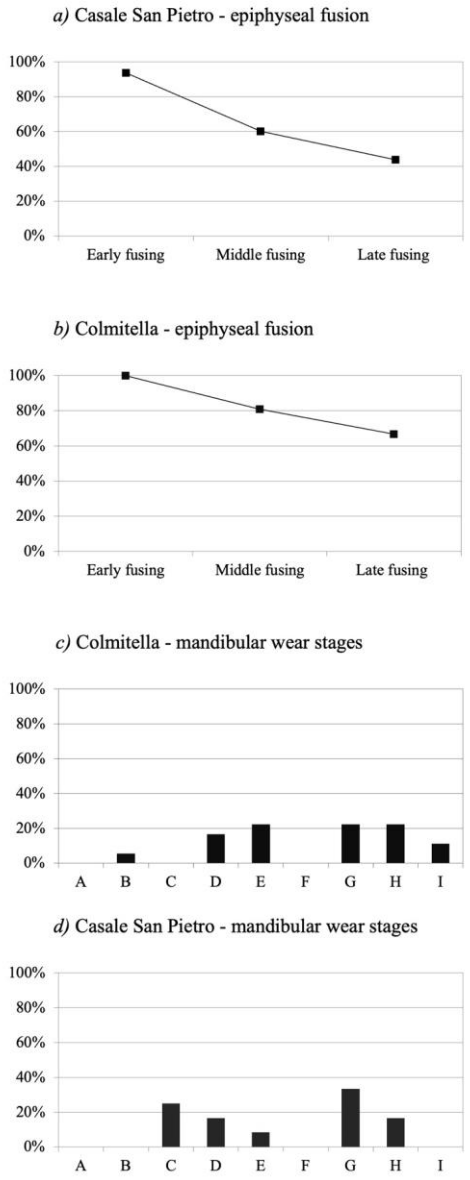


Fig.5 Arab period - rural sites. Percentage of fused sheep/goat bones within each fusion stage (Silver 1969) at Arab rural sites; early fusing stage: 12-24 months; middle fusing stage: 24-36 months; late fusing stage: 36-48 months - a: Casale San Pietro (n:30;12;7); b: Colmitella (n:26;21;8). Frequency of sheep/goat mandibular wear stages (Payne 1973) at Arab rural sites - c: Casale San Pietro (n:12); d: Colmitella (n:18). A: 0-2 months, B: 2-6 months, C: 6-12 months, D: 1-2 years, E: 2-3 years, F: 3-4 years, G: 4-6 years, H: 6-8 years, I: 8-10 years.

The Norman/Aragonese period

In the Norman/Aragonese period some changes in sheep/goat husbandry are visible (Fig. 6). At Corso dei Mille, for example, a higher proportion of individuals (ca. 40%) were culled before reaching three/four years of age (late fusing stage) in comparison to the previous phase (Fig. 6a). At the Norman Palace, ca. 30% of animals were culled before their second-third year of age (middle fusing stage), while a further ca. 40% of animals were slaughtered before reaching three-four years of age (late fusing stage). A smaller proportion of individuals survived into later adulthood (> three-four years of age) (Fig. 6b).

At Norman/Aragonese Mazara del Vallo a higher incidence of individuals survived into late adulthood (ca. 70%) in comparison to the Arab phase, while ca. 20% were culled before reaching their third-fourth year of age (late fusing stage) and the second-third year of age (middle fusing stage; Fig. 6c) respectively. The results obtained from mandibular wear stages at the Norman Palace and Mazara del Vallo corroborate the epiphyseal fusion data (Fig. 6d-e).

In sum, it seems that sheep/goat husbandry in the Norman/Aragonese period was more specialised than in the Arab phase; individuals were mainly exploited for their meat at Corso dei Mille and the Norman Palace, and for wool production - and, to a lesser extent, milk - at Mazara del Vallo.

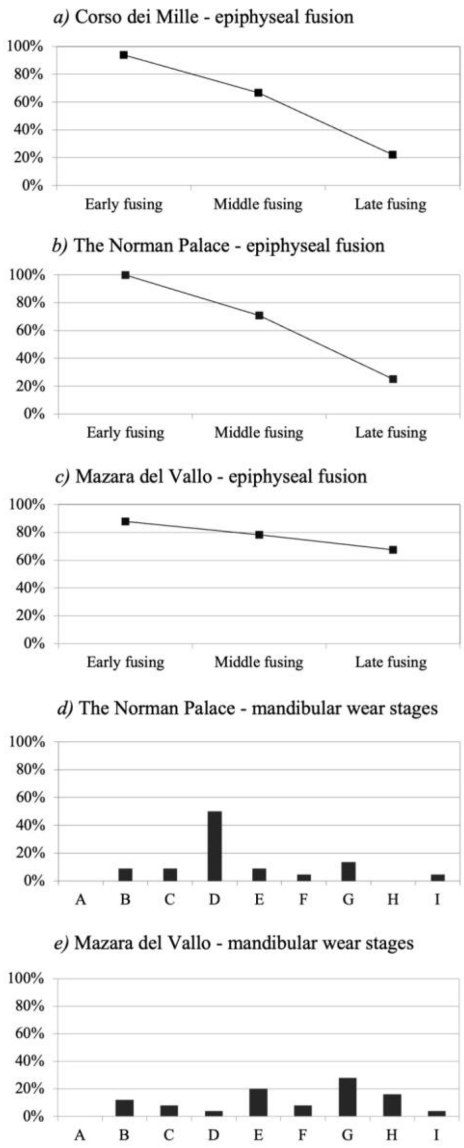


Fig.6 ~~Norman/Aragonese period - urban sites.~~ Percentage of fused sheep/goat bones within each fusion stage (Silver 1969) at Norman/Aragonese urban sites; early fusing stage: 12-24 months; middle fusing stage: 24-36 months; late fusing stage: 36-48 months - a: Corso dei Mille (n:15;2;2); b: the Norman Palace (n:12;17;4); c: Mazara del Vallo (n:58;37;40). Frequency of sheep/goat mandibular wear stages (Payne 1973) at Norman/Aragonese urban sites - d: the Norman Palace

(n:17); e: Mazara del Vallo (n:43). A: 0-2 months, B: 2-6 months, C: 6-12 months, D: 1-2 years, E: 2-3 years, F: 3-4 years, G: 4-6 years, H: 6-8 years, I: 8-10 years.

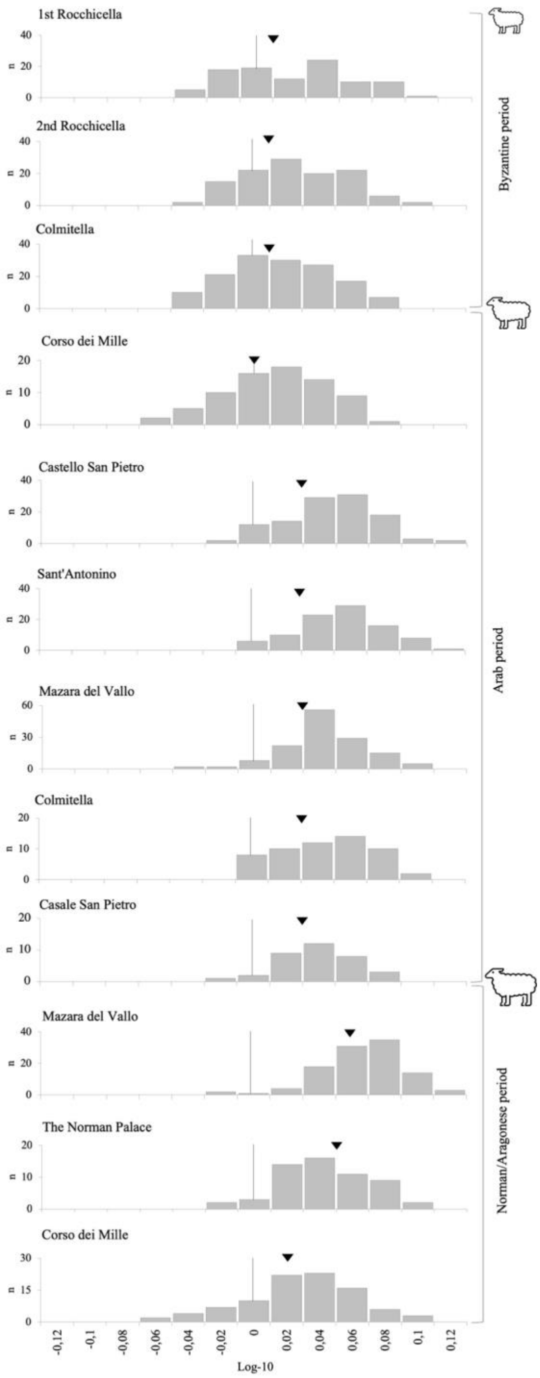
4.2 Biometry

Overall, in most periods and sites the log-ratio histograms of sheep post-cranial bones display a roughly unimodal distribution of data[1] (Fig. 7). In the Byzantine period, no obvious differences in sheep size are visible between the rural sites of Rocchicella and Colmitella. In the later Arab period, sheep are larger in size at Colmitella in comparison to its previous period; such an increase is confirmed by the results of statistical test (see Fig. a; ~~and~~ Tables c~~b~~, d~~e~~ in *Supplementary material*). Sheep from the Arab period at Casale San Pietro are of a similar size to those from contemporary Colmitella.

Sheep size at Arab urban sites is slightly more variable than at rural sites. At Arab Palermo (Sant'Antonino, Castello San Pietro) and Mazara del Vallo the animals are similar in size to those of the contemporary rural sites (Colmitella and Casale San Pietro), but at Corso dei Mille they are smaller.

A further increase in sheep size is attested in the Norman/Aragonese period at the urban sites of the Norman Palace and Mazara del Vallo. In the latter site sheep are larger in comparison to the previous Arab phase, and this is also confirmed by the Student's t-test indicating a statistically significant size increase. Sheep become larger also at Norman/Swabian Corso del Mille, although they are still overall smaller than at contemporary urban sites. In this case, however, the observed increase of sheep size is not statistically significant ~~the observed increase of sheep size is not confirmed by the statistical test~~ (see Fig. ~~-~~a; ~~and~~ Tables c~~b~~, d~~e~~ in *Supplementary material*) and therefore would need verification with larger samples.

[1] Goats were excluded from the biometrical analysis when they could be identified. Overall, identified caprine specimens are likely to be overwhelmingly sheep (see 3. Methodology, 3.3 Biometry).


1st Rocchicella
2nd Rocchicella
Colmitella
Corso dei Mille
Castello San Pietro
Sant'Antonino
Mazara del Vallo
Colmitella
Casale San Pietro
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Arab period
Norman/Aragonese period

Figure 7 Distribution of log-ratio values of sheep post-cranial bone measurements from Byzantine Rocchicella (1st and 2nd phases; n:99;118) and Colmitella (n:146), from Arab Colmitella (n:60), Casale San Pietro (n:55), Corso dei Mille (n:76), Castello San Pietro (n:111), Sant'Antonino (n: 216), Mazara del Vallo (n: 139), and from Norman/Aragonese Mazara del Vallo (109), the Norman Palace (n:68) and Corso dei Mille (n:93). The triangles indicate the logarithmic means; the standard used (black line) is the means of measurements from a sample of unimproved Shetland ewes (Davis 1996).

The large dataset from Mazara del Vallo has provided the opportunity to generate additional log-ratio histograms in which widths and depths ~~from~~ from the bones less influenced by sex differences ~~the less sex-depended bones only~~ were analysed (tibia, calcaneum and astragalus; Fig.8). This mitigated the influence of sexual dimorphism in the assessment of size change between the Arab and the Norman/Aragonese period at the site. As Fig. 8 indicates, a higher incidence of larger measurement characterises the bones from Norman/Aragonese Mazara in comparison to those of the Arab period, thus suggesting an increase in sheep size. Therefore, it is possible to affirm that a genuine increase in sheep size occurred from the Arab to the Norman/Aragonese periods at Mazara, and that differences in the proportion of ewes, wethers and rams are unlikely to lie behind such differences in size.

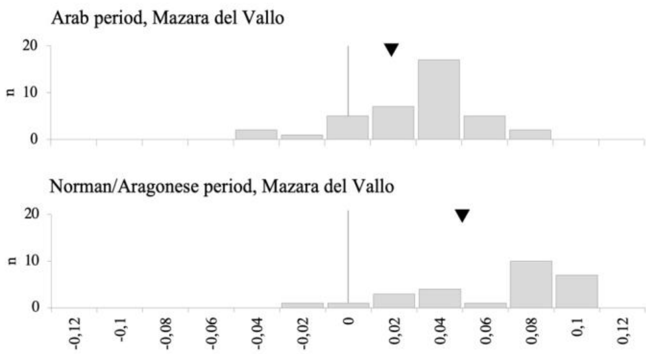

Fig.8 Distribution of log ratio values of sheep post-cranial bone less sex-dependent measurements from Arab (n: 100) and Norman/Aragonese (n: 81) Mazara del Vallo. The triangles indicate the logarithmic means. The standard used (black line) is the means of measurements from a sample of unimproved Shetland ewes (Davis 1996).

5. Discussion

At the two Byzantine sites of Rocchicella and Colmitella sheep/goat husbandry practices seem rather similar. Overall, mature sheep/goat were largely kept until later adulthood, with fewer individuals culled for their meat. At both sites, and especially at Colmitella, there seems to have been a specific interest in wool production, a pattern that has also been observed at the Late Roman - Byzantine sites of Castagna (Agrigento; Johnstone 1997), Kaukana (Ragusa; MacKinnon unp.a), Ganzirri (Messina; Mangano 2001), Sofiana (Enna; MacKinnon unp.b,c,d), and Gerace (Enna; Wilson 2021).

Such specialised husbandry practices are in line with an interest in wool production, which starts to be attested in central and southern Italy since the Late Antiquity/Early Byzantine period. This phenomenon could be a response to the decline in linen imports, which was highly popular in the textile market of the Late Roman period (MacKinnon 2002).

Zooarchaeological data from the Palermo sites presented for the first time in this study~~paper~~ (Corso dei Mille, Sant'Antonino and Castello San Pietro) and Mazara del Vallo, as well as from previous studies (Via Imera, Santa Maria degli Angeli alla Gancia, and Palazzo Bonagia - Palermo; Arcoleo and Sineo 2014; Arcoleo 2015) highlight the prominent role that sheep had in the economy of Arab Sicily (Aniceti and Albarella 2022). The much lower frequency of goat in urban sites (Aniceti 2019) suggests that a few goats may have been herded with sheep in mixed local flocks, a common practice in the Mediterranean Basin (Ramalho Ribeiro et al. 2006). The current evidence suggests that sheep was better represented in Sicilian and Al-Andalusian contexts (Aniceti and Albarella 2022; García-García 2019), while goats were more common in North Africa (e.g., the urban sites of Lepcis Magna, Libyan Valleys, Setif, Chercel, Volubilis, and Quseir al-Qadim; Hamilton-Dyer 2011; Mackinnon 2017; King 2018). Different environmental and climatic conditions could explain such discrepancies, due to the different physiological and behavioral characteristics of the two species: goats tend to be better adapted to severe climatic and environmental conditions, such as semi-desertic or desertic environments, which are more typical of North Africa. In addition, different social and economic needs could have also contributed to a different incidence of sheep and goat; sheep are well-known sources of wool, while goats are better milk producers (Mackinnon 2017).

Sheep/goat exploitation was unspecialized in both urban and rural sites in Arab Sicily, with individuals culled at different age stages. A similar trend has been also detected for most urban sites dated to the Arab period in North Africa (Mackinnon 2017). Such a high level of flexibility in sheep/goat husbandry regimes recalls that practiced by modern pastoral communities in North Africa and the Middle East. In these areas, owning a flock and exploiting it for generalised purposes represents an invaluable economic investment; the exploitation of sheep/goat is highly versatile and can be adapted to economic conditions and changing social needs (Abu-Rabia 1994; MacKinnon 2017).

Unlike Arab Sicily and North Africa, most urban sites from Al-Andalus show more specialised sheep/goat husbandry practices focusing on the production and consumption of meat (Morales-Muñiz et al. 2011). Exceptions to this trend, however, do exist. A more generalised exploitation of sheep/goat was recently suggested, for example, for the Muslim site of Šaqunda (Andalucía; García-García 2019), and this can be indicative of the existence of different pastoral strategies in Al-Andalus (Davis et al. 2008; Moreno-García 2013).

The almost complete absence of published biometrical data from Roman/Byzantine/medieval sites in Sicily does not provide us with the opportunity to interpret our biometric results in the broader context of the island. Zooarchaeological evidence for a size increase in sheep has, however, been detected in other regions conquered by the Arabs. For instance, it has been attested in 12^{th}-13^{th} centuries AD contexts in Portugal (Davis 2008) and in the 8^{th}-10^{th} centuries AD levels of a number of southern Spanish sites (García-García 2019). As higher meat yield is correlated with larger bones in sheep (Hammond 1960), it is likely that the need and will of the Arab administration to replace meat production from the fast-growing and highly productive (but now prohibited) pig was the trigger behind this increase in sheep size, along with the renowned passion for mutton of the Arab invaders (Davis 2008). The Arabs may have improved the sheep locally, for example by improving animal management and/or through selective breeding, or through the importation of a 'larger' breed from North Africa and/or the Middle East, to improve the size of local populations through interbreeding. Historical information from Cairo Genizah indicates that, in the 11^{th}-12^{th} centuries AD, the Mediterranean Sea was perceived as a large, shared market (Goitein 1967; Goldberg 2012). Following Klein (1920), the establishment and development of important trade networks in different areas of the Mediterranean could have led to the introduction of new breeds of sheep from northern Morocco into Arab territories; the Merinos is likely one of the breeds (if not the only one) imported to the Iberian Peninsula~~the Merinos is likely (one of?) the breed(s) imported to the Iberian Peninsula~~. There are several theories about the origins of the Merinos sheep (Sanchez Belda and Sanchez Trujillano 1987); one of these suggests that this breed originated in ~~the course of~~ the 14^{th} century AD as a result of the crossbreeding of coarse-woolled ewes with fine-woolled rams from North Africa (Riu 1983). The hypothesis of the movement of sheep flocks between North Africa and the Iberian Peninsula has partially been proved by genetic studies which, on samples from seven modern Portuguese breeds, highlighted a strong correlation of maternal lineages with those of Middle Eastern and Asian sheep (Pereira et al. 2006). Unlike modern Spain and Portugal, where Merinos are well-established, very few Merino sheep flocks are, however, present nowadays in Sicily. Here, another breed partly of North African origins and now facing extinction is raised: the Barbaresca Siciliana (Fig. 9).

This breed is well-suited to a generalised mode of exploitation, being productive in terms of meat, milk and wool outputs. The Barbaresca Siciliana derives from the crossbreeding of the indigenous Pinzirita sheep with the fat tailed Barbaresca (or Berberine/Berbera) sheep, which is native of North Africa (Bigi and Zanon 2008). Among the autochthonous modern sheep breeds of Sicily, the Barbaresca is one of the largest; therefore, in addition to being a versatile breed, it provides a larger than average amount of meat (Bigi and Zanon 2008). The potential genetic relation of the Barbaresca with North African sheep breeds is still debated (Mastrangelo et al. 2017; 2019).

Fig.9 Barbaresca Siciliana sheep (central Sicily) Photo credit: Nuccio Ciuni.

It is thus tempting to date back the crossbreeding of the autochthonous Pinzirita sheep and the North African Barbaresca to Arab times. This would explain the increase in sheep size revealed by the zooarchaeological analyses. Large sheep, such as the North African Barbaresca, could have been brought by the Arabs into Sicily, as part of a plan to improve animal management. It was probably part of a more general agricultural programme, which included the introduction of new plants and agricultural methods. More efficient techniques of crop production could have also led to the improvement of animal nutrition which would have also contributed to a size increase in sheep. The presence, in Arab Palermo and Mazara, of sheep populations of different size suggests some degree of variability and the co-existence of different breeds. Major urban sites such as Palermo and Mazara would have been most likely supplied from different sources, hence the presence of different size groups.

In the later Norman/Aragonese period, additional changes in the culling strategies of sheep/goat were detected. At all the analysed and comparative sites, such as Brucato (Bossard-Beck 1984), Calathamet (Di Patti et al. 2013), Castello di Fiumedinisi (Villari 1988), Rocca di Entella (Bedini 1999), Segesta (Di Martino 1997), Palazzo Chiaramonte Steri (Di Patti and Lupo 2012), an overall shift from a generalised (typical of the Arab period) to a more specialised sheep/goat husbandry is evident. Most sheep/goat were exploited for meat (and, to a lesser extent, wool) production, with animals generally culled once they had reached their optimum weight. This specific focus on meat consumption, which partially recalls the 'passion for mutton' of the Arabs (Davis 2008), is supported by biometrical analyses on sheep/goat post-cranial bones. An analysis of the less sex-dependent measurements indicates an increase in sheep size in the Norman/Aragonese period of Mazara del Vallo, which is probably independent of any changes in livestock sex ratio. A similar increase in size is also attested at Norman/Swabian Corso dei Mille, although for this site the potential effect of variable sex proportions is more difficult to assess. No diachronic comparisons were possible for the Norman Palace; here, however, sheep are similar in size to those from Norman/Swabian Mazara del Vallo.

6. Conclusion

This study ~~article~~ has highlighted the important role of ~~the~~ analysing ~~study of~~ animal remains in developing the concept of the Arab Agricultural Revolution, one of the most discussed socio-cultural and economic phenomena of medieval Europe. In Sicily, the Arab Agricultural Revolution was not limited to the introduction of new plants/varieties and agricultural techniques, but it also embraced animal husbandry, aiming at a more comprehensive exploitation of the countryside. Additional improvements in the Norman/Aragonese period suggest that the Arab innovations continued to be valued and were, in fact, further developed by the new Christian rulers. The archaeological evidence thus indicates a long-term process of sheep size improvement, reflecting a commonality of purpose in the Arab and later periods. Larger sheep, along with changes in dietary habits ~~the already discussed trends in pork consumption~~ (Aniceti and Albarella 2022), represent one of the many aspects of the troubled process of acceptance, rejection, and adaptation of cultural, religious, and economic elements of the old Arab administration by the new one.

7. Acknowledgements

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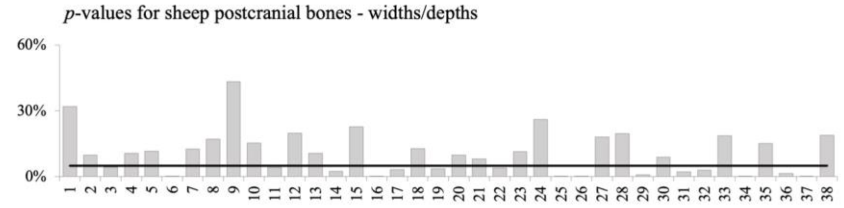
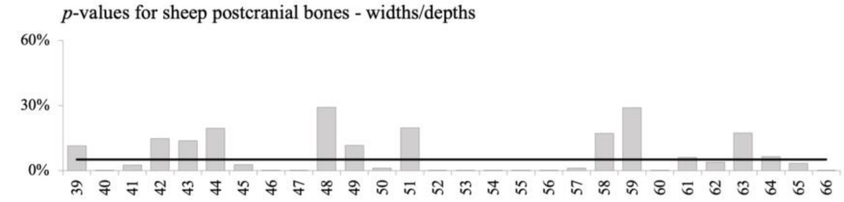
Supplementary material





urban	Sant'Antonino	n:27 – 7%	n:358 – 92%	n:3 – 1%	n:388	n:474
urban	Mazara del Vallo	n:121 – 28%	n:303 – 70%	n:11 – 3%	n:435	n:546

c) Norman/Aragonese period (second ½ 11th- late 13th c. AD)

site type	*name*	*cattle*	*caprines*	*suids*	*NISP main domesticates*	*Total NISP*
urban	Corso dei Mille	n:27 – 13%	n:171– 85%	n:4 – 2%	n:202	n:246
urban	The Norman Palace	n:11 – 4%	n:95 – 38%	n:147 – 58%	n:253	n:286
urban	Mazara del Vallo	n:61 – 20%	n:200 – 66%	n:41 – 14%	n:302	n:427

Table a: NISP counts and frequencies of the three main domesticates (cattle, caprines and suids).

Byzantine period	RO1	RO2	CO	*Total*
sheep	96	172	149	*417*
goat	4	7	23	*34*
sheep/goat	49	2	93	*144*
Total	*149*	*181*	*265*	*595*

Arab period	CO	CASP	CSP	CDM	SANT	MZ	*Total*
sheep	69	140	38	88	223	250	*808*
goat	1	9	1	5	26	17	*59*
sheep/goat	27	82	30	13	109	36	*297*
Total	*97*	*231*	*69*	*106*	*358*	*303*	*1164*

Norman/Aragonese period	CDM	*NP*	*MZ*	*Total*
sheep	88	58	96	*242*
goat	5	1	7	*13*
sheep/goat	13	36	63	*112*
Total	*106*	*95*	*166*	*367*

Table b: Recorded countable elements identified as sheep (*Ovis aries*), goat (*Capra hircus*) and sheep/goat (*Ovis/Capra*) at Rocchicella phase 1 (RO1), Rocchicella 2 (RO2), Colmitella (CO), Castello San Pietro (CASP), Casale San Pietro (CSP), Corso dei Mille (CDM), Sant'Antonino (SANT), the Norman Palace (NP) and Mazara del Vallo (MZ) in the Byzantine, Arab and Norman/Aragonese periods.

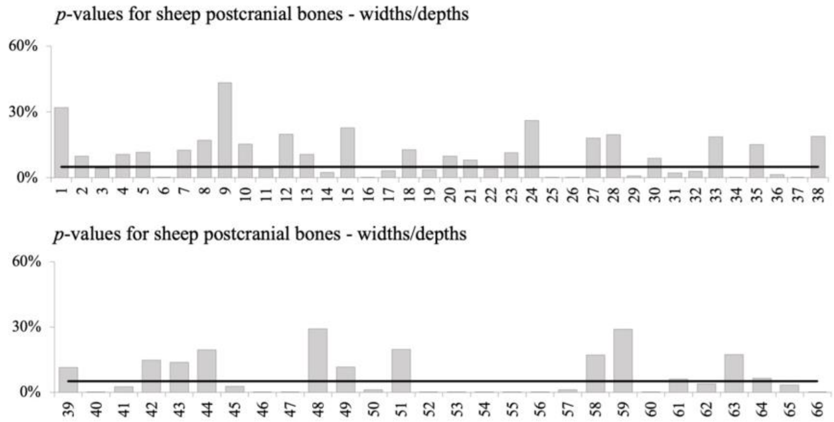


Figure a: Student's t-test *p*-values for sheep/goat post-cranial bone widths/depths. *p*-values assess the probability that the two groups of values being compared are statistically similar. Therefore, low p-values suggest that the difference between the two groups is statistically significant; the threshold usually applied is $p<0.05$ (black line). The numbers listed in the X axis of the graph refer to comparisons as shown in Tables cs.b; ,de.

b)

Period	*Site*	**AR**	**N/S**	**AR**	**N/S**	**AR**	**AR**	**N/A**	**BYZ**	**AR**	**BYZ1**	**BYZ2**	**AR**
		CDM	*CDM*	*SANT*	*NP*	*CSP*	*MZ*	*MZ*	*CO*	*CO*	*RO*	*RO*	*CASP*
AR	*CDM*	-	1	2	3	4	5	6	7	8	9	10	11
N/S	*CDM*	1	-	12	13	14	15	16	17	18	19	20	21
AR	*SANT*	2	12	-	22	23	24	25	26	27	28	29	30
N/S	*NP*	3	13	22	-	31	32	33	34	35	36	37	38
AR	*CSP*	4	14	23	31	-	39	40	41	42	43	44	45
AR	*MZ*	5	15	24	32	39	-	46	47	48	49	50	51
N/A	*MZ*	6	16	25	33	40	46	-	52	53	54	55	56
BYZ	*CO*	7	17	26	34	41	47	52	-	57	58	59	60
AR	*CO*	8	18	27	35	42	48	53	57	-	61	62	63
BYZ1	*RO*	9	19	28	36	43	49	54	58	61	-	64	65
BYZ2	*RO*	10	20	29	37	44	50	55	59	62	64	-	66
AR	*CASP*	11	21	30	38	45	51	56	60	63	65	66	-

Table ca: reference numbers for the statistical tests presented in Figure a.

c)

p-values		**AR**	**N/S**	**AR**	**N/S**	**AR**	**AR**	**N/A**	**BYZ**	**AR**	**BYZ1**	**BYZ2**	**AR**
		CDM	*CDM*	*SANT*	*NP*	*CSP*	*MZ*	*MZ*	*CO*	*CO*	*RO*	*RO*	*CASP*
AR	*CDM*	-	31,97	9,89	4,28	10,58	11,52	0,01	12,49	17,11	43,32	15,38	4,16
N/S	*CDM*	31,97	-	19,80	10,54	2,44	22,70	0,01	3,27	12,71	3,58	9,86	8,02
AR	*SANT*	9,89	19,80	-	3,87	11,36	26,05	0,01	0,13	18,02	19,62	0,86	8,85
N/S	*NP*	4,28	10,54	3,87	-	2,15	3,00	18,61	0,01	15,08	1,37	0,11	18,84
AR	*CSP*	10,58	2,44	11,36	2,15	-	11,42	0,03	2,52	14,71	13,74	19,55	2,77
AR	*MZ*	11,52	22,70	26,05	3,00	11,42	-	0,01	0,19	29,21	11,64	1,20	19,77
N/A	*MZ*	0,01	0,01	0,01	18,61	0,03	0,01	-	0,01	0,14	0,01	0,01	0,09
BYZ	*CO*	12,49	3,27	0,13	0,01	2,52	0,19	0,01	-	1,12	17,12	28,90	0,03
AR	*CO*	17,11	12,71	18,02	15,08	14,71	29,2	0,14	1,12	-	6,02	3,84	17,33
BYZ1	*RO*	43,42	3,58	19,62	1,37	13,74	11,64	0,01	17,12	6,02	-	6,47	3,31
BYZ2	*RO*	15,38	9,86	0,86	0,11	19,55	1,20	0,01	28,90	3,84	6,47	-	0,24
AR	*CASP*	4,16	8,02	8,85	18,84	2,77	19,77	0,09	0,03	17,33	3,31	0,24	-

Table de: complete list of *p*-values (parametric test: Student's *t*-test) from all the comparisons.

8. Bibliography

Abu-Rabia A (1994) The Negev Bedouin and livestock rearing: social, economic, and political aspects. Berg Publishers, Oxford.

Albarella U (2002) 'Size matters': how and why biometry is still important in zooarchaeology. In: Dobney K, O'Connor TP (eds) Bones and the man. Studies in honour of Don Brothwell. Oxbow, Oxford, pp 51-62.

Albarella U, Davis SJM (1994) The Saxon and medieval animal bones excavated 1985-1989 from West Cotton, Northamptonshire. Ancient Monuments Laboratory Report 17/94.

Aleo Nero C (2017) Palermo. Ceramica da contesti urbani di età medievale, circolazione e consumo. Lo scavo nel Convento di Sant'Antonino (2013). In: Atti del XLVIII Convegno Internazionale della Ceramica, Savona, 2015. Centro Ligure per la Storia della Ceramica, Savona, pp.83-98.

Aniceti V (2019) Animals and their roles in the medieval society of Sicily: from Byzantines to Arabs and from Arabs to Norman/Swabians. Unpublished PhD thesis, University of Sheffield, United Kingdom.

Aniceti V, Albarella U (2022) Who's eating pork? Investigating pig breeding and consumption in Byzantine, Islamic and Norman/Aragonese Sicily (7th-14th c. AD). Journal of Archaeological Science: Reports (41):103299.

Arcifa L (2016). Per un nuovo approccio allo studio delle città siciliane nell'Altomedioevo: Catania e Siracusa tra VIII e IX secolo. In: Giuffrida C, Cassia M (ed) Silenziose rivoluzioni: la Sicilia dalla tarda antichità al primo Medioevo, Atti dell'incontro di studio (21-23 maggio, Catania-Piazza Armerina). Edizioni del Prisma, Catania, pp.415-439.

Arcifa L, Bagnera A (2014) Islamizzazione e cultura materiale a Palermo: una riconsiderazione dei contesti ceramici di Castello San Pietro. In: Nef A, Ardizzone F. (eds) Les dynamiques de l'islamisation en Méditerranée centrale et en Sicile: nouvelles propositions et découvertes récentes. École Française de Rome and Edipuglia, Bari, pp.165-195.

Arcifa L, Lesnes E (1997) Primi dati sulle produzioni ceramiche palermitane dal X al XV secolo. In: Démians D'Archimbaud G (ed) La céramique médiévale en Méditerranée. Actes du 6 congres. Aix-en-Provence, 13–18 novembre 1995. Narrations Ed, Aix-en-Provence, pp.405-418

Arcifa L, Maniscalco L (2016). Il perché dopo l'Antico. In: Arcifa L, Maniscalco L (eds) Dopo l'Antico: ricerche di archeologia medievale. Regione Siciliana, Palermo, pp.5-8

Arcoleo L (2015) Indagini archeozoologiche della Palermo antica: la Gancia, Palazzo Bonagia e Via Imera. Unpublished PhD Thesis, Università degli Studi di Palermo, Italy.

Arcoleo L, Sineo L (2014) Analisi archeozoologica di due contesti della città antica di Palermo: la Gancia e i Sili di via Imera (Palermo, IX-X secolo D.C.). In: Nef A, Ardizzone F (eds) Les dynamiques de l'islamisation en Méditerranée centrale et en Sicile. Nouvelles propositions et découvertes récentes. Edipuglia, Bari, pp.301-306.

Barone R (1976) Anatomie comparée des animaux domestiques: ostéologie (1). Vigot frères, Paris.

Battaglia G, Riolo L, Aniceti V (2016) Produzioni artigianali nella Palermo islamica. In: Caminneci V, Parello MC, Rizzo MS (eds) La città che produce. Archeologia della produzione negli spazi urbani. Atti delle Giornate Gregoriane, X Edizione (10-11 dicembre 2016). Edipuglia, Bari, pp.84-91.

Bedini E (1999) I reperti faunistici del palazzo fortificato medievale (SAS 1/2), relazioni preliminari delle campagne di scavo 1992, 1995, 1997 e delle ricognizioni 1998. Annali della Scuola Normale Superiore di Pisa 4(1):1-188.

Bigi D, Zanon A (2008) Atlante delle razze autoctone. Bovini, equini, ovicaprini, suini allevati in Italia. Bologna: Edagricole, Bologna.

Boessneck J (1969) Osteological differences between sheep (Ovis aries Linné) and goat (Capra hircus Linné). In: Brotherwell D, Higgs E (eds) Science in archaeology: a survey of progress and research. Thames and Hudson, London, pp.331-358.

Bossard-Beck C (1984) Le mobilier ostéologique et botanique. In: Pesez JM (ed) Brucato. Histoire et archéologie d'un habitat médiéval en Sicile (2). Collection de l'École Française de Rome 78, École Française de Rome, Rome, pp.615-671.

Butzer KW, Materu JF, Butzer EK, Kraus P (1985) Irrigation Agrosystems in Eastern Spain. Annals of the Association of American Geographers 75 (4):217-18.

Carver M, Molinari A, Aniceti V, Colangeli F, Giannini N, Giovannini F, Hummler M, Mangiaracina CF, Meo A, Orecchioni P (2017) Ricerche 2016 a Castronovo di Sicilia, Sicily in Transition (Progetto ERC advanced grant 2016-693600). Notiziario archeologico della Soprintendenza di Palermo 23.

Carver M, Molinari A, Aniceti V, Colangeli F, Giannini N, Giovannini F, Hummler M, Mangiaracina CF, Meo A, Orecchioni P (2018). Sicily in transition. Interim report of investigations at Castronovo di Sicilia 2016. The Journal of Fasti Online 412.

Carver M, Molinari A, Aniceti V, Capelli C, Colangeli F, Drieu L, Fiorentino G, Giovannini F, Hummler M, Lundy J, Meo A, Monnereau A, Orecchioni P, Primavera M, Ughi A (2019) Sicily in transition. New research on early medieval Sicily, 2017- 2018. The Journal of Fasti Online 437.

Cassai D (2003) La vita quotidiana a Mazara del Vallo (TP) in età islamica: i “pozzi di butto” di via Tenente Romano. Unpublished PhD Thesis, Università degli Studi di Siena, Italy.

Civantos JMM (2011) Working in landscape archaeology: the social and territorial significance of the agricultural revolution in Al-Andalus. Early Medieval Europe 19:385-410.

Davis SJ (1996) Measurements of a group of adult females Shetland sheep skeletons from a single flock: a baseline for zooarchaeologists. Journal of Archaeological Science 23:593-612.

Davis SJ (2008) Zooarchaeological evidence for Moslem and Christian improvements of sheep and cattle in Portugal. Journal of Archaeological Science 35(4):991-1010.

Davis SJ, Gonçalves MJ, Gabriel S (2008) Animal remains from a Moslem period (12^{th}/13^{th} century AD) lixeira (garbage dump) in Silves, Algarve, Portugal. Revista Portuguesa de Arqueologia 11:183-258.

Decker M (2009) Plants and Progresses: rethinking the Islamic Agricultural Revolution. Journal of World History 20(2):187-206.

Di Martino S (1997) Le analisi archeozoologiche. In Molinari A (ed) Segesta II. Il castello e la moschea (scavi 1989-1995). Flaccovio, Palermo, pp.259-268.

Di Patti C, Lupo F (2012) Analisi del complesso faunistico di palazzo Steri (PA): dai Normanni ai Viceré spagnoli (IX-XV sec.). In: De Grossi Mazzorin J, Sacca` D, Tozzi C (eds) Atti del VI Convegno Nazionale di Archeozoologia, Provincia di Lucca, pp.267-274.

Di Patti C, Di Salvo R, Di Trapani F, Schimmenti V (2013). Les restes faunistiques. In: Lesnes E, Poisson JM. (eds) Calathamet. Archéologie et histoire d'un château normand en Sicile. École Française de Rome, Rome, pp.271-286.

Di Stefano CA, De Floris MH, Arcifa L, Pesez JM (1989). Palerme, quartier Castello San Pietro. MEFRM 101(1):332-350.

Ewbank JM, Phillipson DW, Whitehouse RD, Higgs ES (1964) Sheep in the Iron Age: a method of study. Proceedings of the Prehistoric Society 30:423–426.

Fiorentino G, Porta M, Primavera M, Sellitto A (2022)~~(in press)~~ Mazara tra innovazione e continuità: il contributo dell'archeobotanica alla ricostruzione dei paesaggi, dei sistemi agricoli e delle abitudini alimentari tra Fase Bizantina ed Età Moderna. In: Molinari A, Meo A (eds) Mazara/Mazar: nel ventre della città medievale (secoli VII-XV). Biblioteca di Archeologia Medievale. All'Insegna del Giglio: Firenze.

Fuks D, Amichay O, Weiss E (2020) Innovation or preservation? Abbasid aubergines, archaeobotany, and the Islamic Green Revolution. Archaeological and Anthropological Science (12):50.

García-García M. (2019) Explotación y consumo de los animales en el sudeste de la península ibérica durante la Alta Edad Media (ss. VII-XII): perspectivas históricas y arqueozoológicas. PhD Thesis, University of Granada, Spain.

Garcìa Maceira A (1876) Apuntes y noticias sobre la agricoltura de los àrabes españoles, Zamora.

Goitein SD (1967) A Mediterrenean society. The Jewish communities of the Arab world as portrayed in the documents of the Cairo Geniza. Economic Foundations (1). University of California Press, Los Angeles.

Goldberg J (2012) Trade and Institutions in the Medieval Mediterranean: The Geniza Merchants and their Business World. Cambridge University Press, Cambridge.

Grayson DK (1984) Quantitative zooarchaeology. Academic Press, Orlando

Halstead P, Collins P, Isaakidou V (2002) Sorting the sheep from the goats: morphological distinctions between the mandibles and mandibular teeth of adult Ovis and Capra. Journal of Archaeological Science 29:545-553.

Hamilton-Dyer S (2011) Faunal remains. In: Peacock D, Blue L (eds) Myos Hormos-Quseir al-Qadim. Roman and Islamic ports on the Red Sea (2): Finds from the excavations 1999-2003. Archaeopress, Oxford, pp.245-288

Hammond J (1960) Farm animals. Their breeding, growth and inheritance. Edward Arnold: London.

King A (2018) The Faunal Remains. In: Fentress E, Limane H (eds) Volubilis après Rome. Brill, Leiden and Boston, pp.349-365.

Johns J (1985) A Green Revolution? Journal of African History 25(3):343-44.

Johnstone, J (1997) Technical report: Preliminary results from the investigation of vertebrate remains from Castagna, Sicily (site code: CA94). Reports from the Environmental Archaeology Unit, York.

Klein J (1920) The Mesta; a study in Spanish economic history, 1273-1836. Hardpress, Saskatoon.

Kratochvil Z (1969) Species criteria on the distal section of the tibia in Ovis ammon F. aries L. and Capra aegagrus F. hircus L. Acta Veterinaria 38:483-490.

Lyman RL (2008) Quantitative palaeozoology. Cambridge University Press, Cambridge.

MacKinnon M (2002) The role of caprines in Roman Italy: idealized and realistic reconstructions using ancient textual and zooarchaeological data. In: Santillo Frizell B (ed) PECUS. Man and animal in antiquity. Proceedings of the conference at the Swedish Institute in Rome, September 9-12, 2002. The Swedish Institute in Rome, Rome, pp.54-60.

MacKinnon M (2017) Animals, acculturation, and colonisation in ancient and Islamic North Africa. In: Albarella U, Rizzetto M, Vickers K, Russ H and Viner-Daniels S (eds) The Oxford Handbook of Zooarchaeology. Oxford University Press, Oxford, pp.466-478.

MacKinnon, M (Unpublished report a) Kaukana: Preliminary Zooarchaeological Report.

MacKinnon M (Unpublished report b) Sofiana (Sicily) – Some notes on the faunal remains from the 2012 campaign.

MacKinnon M (Unpublished report c) Sofiana (Sicily) – Some notes on the faunal remains from the 2013 campaign.

MacKinnon M (Unpublished report d) Sofiana (Sicily) – Preliminary notes on faunal materials from the 2014-16 excavation season (with some comparisons to earlier years).

Mangano G (2001) Le faune di Ganzirri. In: Bacci G, Tigano G (eds) Da Zancle a Messina. Sicania, Messina, pp.261-261.

Maniscalco L (2008). Le fasi di vita attestate nell'area davanti alla grotta. In: Maniscalco L (ed), Il santuario dei Palici: un centro nella valle dei Margi. Regione Siciliana, Palermo, pp.66-128.

Mastrangelo S, Portolano B, Di Gerlando R, Ciampolini R, Tolone M, Sardina MT, The International Sheep Genomic Consortium (2017) Genome-wide analysis in endangered populations: a case study in Barbaresca sheep. Animal 11(7):1107-1116.

Mastrangelo S, Bahbahani H, Moioli B, Ahbara A, Al Abri M, Almathen F, da Silva A, Belabdi I, Portolano B, Mwacharo JM, Hanotte O, Pilla F, Ciani E (2019) Novel and known signals of selection for fat deposition in domestic sheep breeds from Africa and Eurasia. PLoS ONE 14(6):e0209632.

Meadow RH (1999) The use of size index scaling techniques for research on archaeozoological collections from the Middle East. In: Becker C, Manhart H, Peters J, Schibler J (eds) Historia animalium ex ossibus. Beiträge zur Paläoanatomie, Archäologie, Ägyptologie, Ethnologie und Geschichte der Tiermedizin. Festschrift für Angela von den Driesch. Verlag Marie Leidorf GmbH, Rahden, pp.285-300.

Molinari A (2010) Paesaggi rurali e formazioni sociali nella Sicilia Islamica, Normanna e Sveva (secoli X-XIII). Archeologia Medievale 37:229-245.

Molinari A, Cassai D (2006) La Sicilia ed il Mediterraneo nel XIII secolo: importazioni ed esportazione di ceramiche fini e da trasporto. In: Lavagna R (ed.) Atti XXXVII Convegno Internazionale della Ceramica, Albisola. All'Insegna del Giglio, Florence, pp.37-38.

Molinari A, Meo A (in press) Mazara, Mazar: nel ventre della città medievale (secoli VII-XV). Edizione degli scavi, in Via Tenente Gaspare Romano. All'Insegna del Giglio, Firenze.

Morales-Muñiz A, Moreno-García A, Izquierdo R, Llorente-Rodriguez L, Morales-Muñiz DC (2011) 711 AD: ¿El Origen de una Disyunción Alimentaria? Zona Arqueologica 15:301-319.

Moreno-García M (2013) Gestión y aprovechamiento de cabañas ganaderas en al-Andalus: aportaciones desde la arqueozoología. Debates de Arqueología Medieval 3:75-98.

Payne S (1973) Kill-off patterns in sheep and goats: the mandibles from Aşvan Kale. Anatolian Studies 23:281-303.

Payne S (1985) Morphological distinctions between the mandibular teeth of young sheep, Ovis, and goats, Capra. Journal of Archaeological Science 12:139-147.

Payne S (1987) Reference codes for wear states in the mandibular cheek teeth of sheep and goats. Journal of Archaeological Science 14:609-614.

Payne S, Bull G (1988) Components of variation in measurements of pig bones and teeth, and use of measurements to distinguish wild from domestic remains. Archaeozoologia 2:27-66.

Pereira F, Davis SJ, Pereira L, McEvoy B, Bradley B, Amorim A (2006) Genetic signatures of a Mediterranean influence in Iberian Peninsula sheep husbandry. Molecular Biology and Evolution 23(7):140-146.

Primavera M (2018) Introduzione di nuove piante e innovazioni agronomiche nella Sicilia medievale: il contributo dell'archeobotanica alla rivoluzione agricola araba di Andrew Watson. Archeologia Medievale 45:439-444.

Ramalho Ribeiro JMC, Horta AEM, Mosconi M, Rosati A (2006) Animal products from the Mediterranean area. Wageningen Academic Publishers, the Netherlands.

Riu M. (1983) The woollen industry in Catalonia in the later Middle Ages. In: Harte NB, Ponting KG (eds) Cloth and clothing in medieval Europe: essays in memory of Prof. E. M. Carus-Wilson. Heinemann Educational Books and Pasold Research Fund, London, pp.205-229.

Rizzo MS, Danile L, Romano D, Scibona M, Zambito L (2012). Il villaggio di Colmitella (Racalmuto, AG): primi dati dallo scavo archeologico di un insediamento rurale di età altomedievale e medievale. In: Redi F, Forgione A (eds) VI Congresso Nazionale di Archeologia Medievale. All'Insegna del Giglio, Firenze, pp.419-424

Rizzo MS, Romano D (2012). I butti del villaggio rurale di Colmitella (Racalmuto, AG). Archeologia Postmedievale 16:99-107.

Rizzo MS, Danile L, Zambito L (2014). L'insediamento rurale nel territorio di Agrigento: nuovi dati da prospezioni e scavi. In: Nef A, Ardizzone F (eds) Les dynamiques de l'islamisation en Méditerranée centrale et en Sicile: nouvelles propositions et découvertes récentes. École Française de Rome and Edipuglia, Rome and Bari, pp.351-363.

Rizzo MS, Romano D, Scibona M (2015). Il villaggio di Colmitella (Racalmuto, AG): le fasi altomedievali. In: Arthur P., Imperiale ML (eds.) VII Congresso Nazionale di Archeologia Medievale, Palazzo Turrisi (2). All'Insegna del Giglio, Firenze, pp.419-424.

Ros, J., S. Gilotte, S. Gasc, P. Senac. 2016. *Islamic diet and agricultural practices in rural al-Andalus*. Oral presentation at the 22nd Annual meeting of the European Association of Archaeologists, Vilnius (Lithuania).

Salvagno L, Albarella U (2017) A morphometric system to distinguish sheep and goat postcranial bones. PLoS ONE 12(6):e0178543.

Sanchez-Belda A, Sanchez-Trujillano MC (1987) Razas ovinas españolas. Instituto Nacional de Reforma y Desarrollo Agrario, Madrid.

Schmid E (1972) Atlas of animal bones. For prehistorians, archaeologists and quaternary geologists. Elsevier Publishing Company, London.

Silver IA (1969) The ageing of domestic animals. In: Brothwell DR, Higgs E (eds) Science in archaeology. Thames and Hudson, London.

Simpson GG, Roe A, Lewontin RC (1960) Quantitative zoology. Harcourt Brace, New York.

Squatriti P (2014) Of Seeds, Seasons, and Seas: Andrew Watson's Medieval Agrarian Revolution Forty Years Later. The Journal of Economic History 74(4):1205-1220.

Todaro P, Barbera G, Castrorao Barba A, Bazan G (2020) Qanāts and historical irrigated landscapes in Palermo’s suburban area (Sicily). European Journal of Postclassical Archaeology 10:335-370.

Vassallo S, Aleo Nero C, Battaglia G, Calascibetta G, Chiovaro M, Cucco RM, Sapia (2016) Attività 2015 della sezione per i Beni Archeologici della Soprintendenza di Palermo. Notiziario Archeologico della Soprintendenza di Palermo 9.

Vassallo S, Aleo Nero C, Battaglia G, Chiovaro M, Cucco RM (2018) Attività` 2016 della sezione per i Beni Archeologici della Soprintendenza di Palermo. Notiziario Archeologico della Soprintendenza di Palermo 33.

Villari P (1988) Resti faunistici da uno scavo medievale del Castello di Fiumedinisi (Messina). Archeologia Medievale 15:609-642.

von den Driesch A (1976) A guide to the measurement of animal bones from archaeological sites. Peabody Museum, Harvard.

Watson AM (1974) The Arab Agricultural Revolution and its Diffusion, 700-1100. Journal of Economic History 34(1):8-35.

Watson AM (1983) Agricultural innovation in the early Islamic world: the diffusion of crops and farming techniques, 700-1100. Cambridge University Press, Cambridge.

Wilson, RJA (2021) UBC Excavations of the Roman Villa at Gerace, Sicily: Results of the 2018 Season. Mouseion (17):95-212.

Zeder M, Lapham HA (2010) Assessing the reliability of criteria used to identify postcranial bones in sheep, Ovis, and goats, Capra. Journal of Archaeological Science 37:2887-2905.

Zeder M, Pilaar SE (2010) Assessing the reliability of criteria used to identify mandibles and mandibular teeth in sheep, Ovis, and goats, Capra. Journal of Archaeological Science 37:225-242.

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