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Diet in high mediaeval florence through stable isotope analysis of carbon, nitrogen and sulphur

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ABSTRACT

In this paper, we aim to reconstruct the dietary habits of supposedly lower rank nobles or middle-class High Middle Ages individuals recovered from the cloister arcade of San Pier Scheraggio within the Uffizi Museum complex in Florence, Italy. Notably, the High Middle Ages was a period of cultural and social changes, which is partly reflected in the dietary habits, as suggested by historical sources. Here we apply stable carbon, nitrogen, and sulphur isotope analysis on humans (n = 34) and animals (n = 13) from San Pier Scheraggio to directly investigate food consumption in this peculiar assemblage. The diet of human individuals was based on terrestrial C_3 sources without clear contribution of marine fish (δ^{13}C mean and 1SD: −19.5 ± 0.7 ‰; δ^{15}N mean and 1SD: 9.6 ± 0.4 ‰; δ^{34}S values are mean and 1SD: 7.6 ± 1.2 ‰). The comparison with animal and human samples from other Italian Middle Ages contexts shows that the overall diet of the population buried at San Pier Scheraggio is in line with that of other mediaeval communities in Italy, although with a generally higher contribution of terrestrial animal products. Our data seem to suggest that at the site there was no dietary differentiation concerning age at death or biological sex of the individuals. Some differences, however, can be outlined, for example, in the contribution of C_4 crops. In addition to this, we identify two individuals as possible non-locals.

1. Introduction

Changes in food habits are often linked to economic, cultural, and religious influences (Gismondi et al., 2020; Marciniak, 2011; Zeder, 2011). However, as denoted by Reitsema et al. (2017), devotion to traditions and resilience can sometimes lead to resistance to dietary changes, even during extensive religious and cultural events. The Middle Ages was a period of profound social change that was also reflected in people's food practices. For example, diet appears to be different according to social status during the transition from the Early to the High/Late Middle Ages. This was partly driven by the Church's imposition and by the growth of the market economy (Spufford, 2003; Varano et al., 2020). Written sources help understand past phenomena, but they are largely biased as they are often representative of the élite (Reitsema et al., 2012). For this reason, it is fundamental to use methods that are not affected by contextual and cultural biases. With this aim, stable isotope analysis of carbon and nitrogen of bone collagen has been used to explore how food dietary habits changed in mediaeval time, in Italy (Amorim et al., 2018; Baldoni et al., 2016, 2019, 2021; Buonincontri et al., 2017; Ciaffi et al., 2015; Cocozza et al., 2022; Fiorin et al., 2021; Gismondi et al., 2018, 2020; Laffranchi et al., 2020; Marinato, 2016, 2017, 2018; Maxwell, 2019; Nitsch, 2012; O'Connell et al., 2019; Paladin et al., 2020; Pescucci et al., 2013; Reitsema et al., 2016; Reitsema and Vercellotti, 2012; Ricci et al., 2012; Riccomi et al., 2020; Rolandsen et al., 2019; Salamon et al., 2008; Scorrano et al., 2014; Tafuri et al., 2018; Torino et al., 2015; Varano et al., 2020; Viva et al.,

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2021). However, these isotopic investigations mainly focus on rural rather than urban settlements, with some notable exceptions, such as Rome. Our research offers important insights into mediaeval Italy for three main reasons: i) we provide the first direct evidence of diet in Florence during the Middle Ages; ii) we contribute with new data from the High Middle Ages, a crucial transitional period that lacks sufficient isotopic studies; and iii) we explore potential differences in food consumption based on social class.

1.1. The church of San Pier Scheraggio, Florence, Italy

The city of Florence, located in the region of Tuscany, Italy (Fig. 1**a**), is situated ca. 80 km from the Tyrrhenian coast, on the banks of the Arno River (Fig. 1**b**). The individuals analysed come from a recent excavation below the Uffizi Museum complex in the former San Pier Scheraggio church in Via della Ninna (Fig. 1**c**).

According to D'Aquino, (2015) at the beginning of the XI century CE, the area that would later house the San Pier Scheraggio church was rural with small buildings made of perishable materials. Over the course of the XI and XII centuries, the area underwent an urbanistic and demographic expansion. This transformation was marked by the adjustments of the walking surfaces together with major masonry projects, including the construction of the church of San Pier Scheraggio, the extension of the defensive walls up to the Arno, and the construction of two towers. These towers were owned by middle-class families, while next to them there were buildings allocated to the lower classes (Scampoli, 2010). During the XI century CE, a fluvial port is documented near San Remigio, close to San Pier Scheraggio (Scampoli, 2010). Starting from this period, cities in Italy began to experience significant urban growth, primarily driven by migration (Carocci, 2011). Florence, in particular, reached 20,000 inhabitants in the High Middle Ages (Mariotti et al., 2015). During this period, the church and the towers were the main possessions of the Uberti family (Bruttini, 2011; D'Aquino, 2015). The Ubertis were influential members of the Ghibellines faction, which supported the Holy Roman Emperor in opposition to the Guelphs, who aligned with the Pope during a period of intense political instability. Ghibellines were decisively defeated by the Guelphs in 1260 CE (D'Aquino, 2015). The defeat of the Ghibellines faction led to the exile of the Uberti family, followed by their prosecution and the *damnatio memoriae,* erasing them from official records (Canaccini, 2021; Milani, 2010). It is argued that this is the reason behind the profanation of their tombs in San Pier Scheraggio (Canaccini, 2014; Ottokar, 1948).

During the end of the XII century and the beginning of the XIII century, the area underwent a further significant urbanistic expansion driven, probably, by rich families (Scampoli, 2010). By that time, the church was located near the walls, and, just outside the walls, at least until the XIII century CE, the area had a strong rural vocation (Francovich et al., 2007a). At the end of the XVI century CE, the church was partially destroyed for the construction of the Uffizi complex. The complex was first used as the seat of the *Uffici*, the magistracies of the city. Only from 1769 CE, the vast art collection stored during the period in the Uffizi complex was organised and opened to the public.

The recent excavations (2015) of the Uffizi complex revealed nine tombs within San Pier Scheraggio's cloister arcades. Of these, seven were constructed with stone walls and sealed with sandstone slabs, while the remaining two were pit graves. Notably, all the tombs contained multiple individuals superimposed, with some showing signs of reduction, and others presenting unarticulated bone assemblages. The articulated skeletons exhibit signs of compression, indicating that they were positioned in restricted spaces to accommodate additional

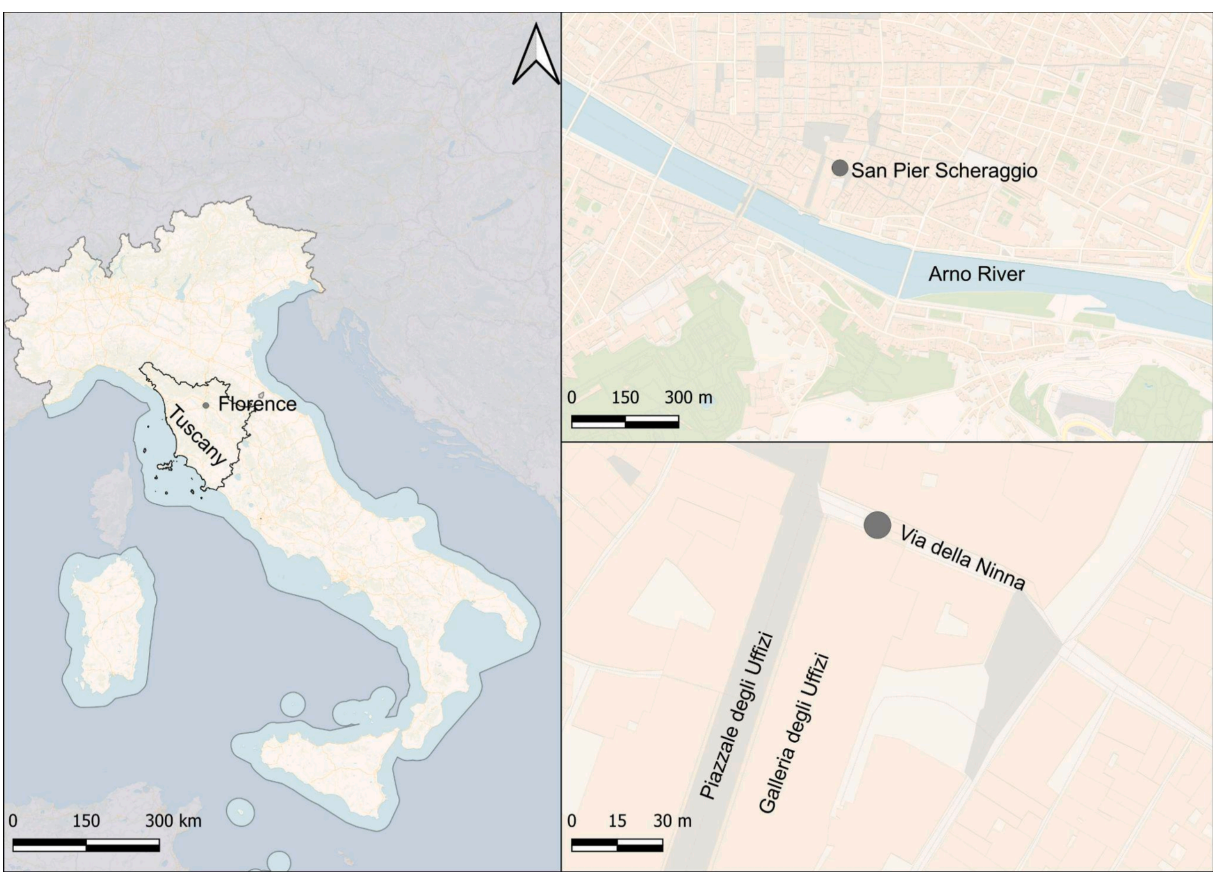

Fig. 1. Geographical position of San Pier Scheraggio in relation to a) Italy and Tuscany (Map tiles by CartoDB, under CC BY 3.0. Data by OpenStreetMap, under ODbL, modified); b) Florence (Map tiles by CartoDB, under CC BY 3.0. Data by OpenStreetMap, under ODbL, modified); and c) Via della Ninna (Map tiles by CartoDB, under CC BY 3.0. Data by OpenStreetMap, under ODbL, modified).

individuals within the same grave. We cannot assess if this phenomenon was associated with kinship burial at this stage. Due to the absence of pottery associated with the inhumations, we can only refer to absolute dating on the bones: some of the individuals unearthed were radiocarbon-dated, placing the burials in the High Middle Ages (XI-XIII centuries CE; Riga and Gori forthcoming).

1.2. Italy and Tuscany from the Early to the High Middle Ages

In post-classical Italy,the collapse of the Roman economy and the resulting depopulation of cities led to a return to a subsistence-based economy (Francovich and Hodges, 2003; Valenti, 2010). This economy was relied on a combination of foraging, animal husbandry, hunting and farming (Valenti 2004; 2008). As a result, Early mediaeval Tuscany was characterised by hilltop villages (Francovich et al., 2007a). Over time, a new stability gave rise to a more complex system, with at least portion of the population able to afford more expensive commodities, such as meat (Buonincontri et al., 2017). Only in the later Early mediaeval phase (VIII-IXth century), as attested by both historical and archaeological sources (Valenti, 2008; Francovich, 2007b), a social hierarchy began to arise. The end of Lombard rule in 774 CE, following the Frankish conquest, helped to establish this hierarchy (Wickham, 2005). This brought to the imposition of a Carolingian manorial system, where a landlord (*dominus*) controlled the economy and the village's lands (Francovich, 2007; Valenti 2008). During this period there was a clear organisation of farming, animal husbandry, and craftsmanship (Valenti 2010). Archaeobotanical data from this period indicates the cultivation of valuable crops also in the proximity of Florence (Buonincontri et al., 2014, 2017; Mariotti et al., 2015).

From the IX to the XII centuries CE several hilltop villages underwent further modifications that led to the appearance of castles (*Castelli*) (Wickham, 1988). Francovich (2007b) estimated that over 60 % of *Castelli* excavated were superimposed onto villages.

Starting from the High Middle Ages (XI century CE) and continuing through the Late Middle Ages, the manorial court economic system gradually gave way to the formation of the *Communi,* a town-based political system, that replaced the post-Carolingian system (Fumagalli, 1985). As demand for food and goods increased, marketplaces expanded (Wickham 1988), leading to the rise of the market economy that eventually led to social inequality (Spufford, 2003). However, single cases might differ from this general picture, which we believe is an additional reason for carrying out targeted studies on food practices in mediaeval contexts.

1.2.1. Diet in mediaeval Italy and Tuscany

During the Early Middle Ages, in Italy, the daily diet was mainly composed of different types of plants and terrestrial animal products that were also affordable for the lower classes, while fish was rarely consumed (Baldoni et al., 2021; Montanari, 2012; Prowse et al., 2004; Riccomi et al., 2020; Salamon et al., 2008). However, in the Late Middle Ages, the Christian imposition of abstinence from the consumption of meat for almost 1/3 of the year (Salamon et al., 2008) led to increasing consumption of fish and secondary animal products (Ciaffi et al., 2015; Gismondi et al., 2018; Zug Tucci, 1984). In this period, the disparity between low and high social status became more evident in food practices (Adamson, 2004; Baldoni et al., 2021; Barbiera and Dalla-Zuanna, 2009; Montanari, 1993; Reitsema and Vercellotti, 2012). Notably, the consumption of C_4 crops (such as broomcorn millet, foxtail millet, and sorghum) increased among low-status individuals (Patrone, 1981; Reitsema and Vercellotti, 2012), while animal products became a privilege of the upper classes (Montanari, 2012, 1988). Spices were considered an exclusive ingredient, and among them, sugar was one of the most important (Montanari, 2000). Imported by the Arabs during their conquests, sugar was grown in Sicily at the beginning of the 9th century CE, but its flourishing production was attested only at the end of the XIII century CE. As stated by Sato (2015), sugar is consistently imported between the XII and XIII century CE.

Isotopic studies of human remains provide evidence of the shift from the Early to the Late Middle Ages. During the Early Middle Ages, both low (Marinato, 2014; 2018; Riccomi et al., 2020) and middle (Marinato, 2014; Maxwell, 2019; Pescucci et al., 2013) status people, along with high status individuals (Maxwell, 2019), showed a relatively high input of terrestrial animal products in their diet. On the contrary, in the later period, differences associated with social status in animal products and C_4 plants consumption were found (Reitsema et al., 2012). Furthermore, in Late Middle Ages Rome (XV century), Salamon and colleagues (2008), found evidence of fish consumption in some individuals, which the authors associated with privileged status.

The transitional period between the Early and Late Middle Ages, known as High Middle Ages, is crucial in understanding shifts in dietary habits in medieval Italy. However, it is one of the least studied periods in terms of isotopic analysis. To our knowledge, only 190 individuals from the High Middle Ages were studied so far in Italy, whereas 690 were from the Early Middle Ages and 250 were from the Late Middle Ages (Cocozza et al. 2022). This calls for an increase in isotopic research for this period, as it was characterised by major social and economic changes that are worthy of further analysis. Moreover, there is a lack of studies exploring the diets of middle- and upper-class individuals, therefore making it difficult to investigate social inequality in mediaeval times. It is worth noting that the individuals buried in the cloister arcade of San Pier Scheraggio concentrate in proximity to the perimetral wall, most likely a privileged burial position (Salvestrini et al., 2007). According to the *converso* Giovanni (Salvestrini et al., 2007), regarding High Middle Ages Bologna, this location was possibly reserved for lower rank nobles and relatively wealthy individuals, as happened in Verona for the commissioner of the restoration of the cloister (Coden, 2018). Instead, for monasteries, such location was privileged for monks both in Ravenna (Ferreri, 2017) and Altopascio (LU) (Fornaciari et al., 2014). A similar case is the church in Castelletto Cervo (BI) from XI-XII century CE, where in the cloister arcades reused tombs where both males and females were buried were found, with at least one of them related to a chivalry, indicating that it was a laic privileged burial position (Destefanis, 2016).

To our knowledge, diet in mediaeval Tuscany was not investigated in detail by historical sources. Nevertheless, residue analysis of vessels and archaeobotanical studies have been recently applied in this area. Residue analysis on rural and urban settlements has detected the presence of cholesterol extensively (Buonincontri et al. 2007, 2017; Giorgi et al. 2010; Salvini et al. 2008), suggesting the consumption of animal products. Instead, the archaeobotanical investigation carried out by Buonincontri and colleagues (2017) has revealed the importance, in the urban area of Florence (XIII century), of the contribution of millet. It also showed the presence of more drought-resistant C_3 crops such as wheat, barley, and emmer.

1.3. Carbon, nitrogen and sulphur stable isotopes

For almost half a century, stable isotope analysis has provided direct insight into the reconstruction of human lives (Ambrose and Krigbaum, 2003; Schoeninger, 2010). Notably, the analysis of stable carbon, nitrogen and sulphur isotopes of bone collagen provides evidence of the dietary habits of the individual investigated. The isotopic composition of bone collagen is used to study the diet of an individual several years prior to death, depending on the bone element analysed (Ambrose and Norr, 1993; Hedges et al., 2007). Carbon isotope values ($\delta^{13}C$) can be used to distinguish between plants depending on their metabolic pathways and, with the same principle, their consumers. C_3 plants, present more ^{13}C-depleted $\delta^{13}C$ values, normally ranging from −29 ‰ and −18 ‰ (Ambrose and Norr, 1993; Pollard et al., 2016; van der Merwe and Medina, 1991); instead, C_4 plants exhibit $\delta^{13}C$ values ranging from −16 ‰ and −12 ‰ (Ehleringer and Monson, 1993). Carbon isotopes make it possible to distinguish between marine and terrestrial environments since marine foodstuffs tend to be ^{13}C-enriched compared to terrestrial C_3 plants (Sealy, 1987). Nitrogen isotopic values (δ^{15}N) are used to detect the consumption of animal products thanks to a trophic level enrichment of 3–6 ‰ that is expected at each step of the trophic chain (Ambrose, 1990; O'Connell et al., 2012; Schoeninger, 2010; Schoeninger and DeNiro, 1984). Since, in general, organisms from aquatic environments exhibit higher δ^{15}N values compared to those from terrestrial ecosystems, δ^{15}N values can also be used to discriminate between the two (Schoeninger et al., 1983). Sulphur isotopic values (δ^{34}S) do not vary significantly along the trophic chain (Nehlich, 2015), and higher values (ca. 20 ‰) are found in marine ecosystems (Rees et al., 1978), while terrestrial and freshwater values vary from −20 ‰ to 30 ‰ and are more dependent on the geological background (Faure and Mensing, 2013) where the higher values are generally from oceanic sediments (Nehlich, 2015). Therefore, δ^{34}S values can be used to characterise the influence of aquatic environments – either freshwater or marine – in the diet (Nehlich, 2015). Additionally, since terrestrial δ^{34}S values are affected by the "sea-spray effect" in the proximity to the coasts and since they vary significantly with the geology, when δ^{34}S are associated with other dietary proxies, they can also be used as a mobility proxy (Katzenberg and Krouse, 1989; Richards, 2023). Furthermore, although the possible range of δ^{34}S is potentially very broad, at a local scale, such a range will tend to be narrower (Nehlich et al., 2013) making sulphur isotope suitable as a locality indicator.

2. Materials and methods

A total of 34 human adult individuals buried in 9 tombs was selected and sampled for stable isotope analysis. For each individual, sex and age at death were estimated using standard methods: cranial and pelvic morphology, along with post-cranial skeletal morphometrics, were employed to assess the sex of adult individuals (Acsádi and Nemeskéri, 1970; Olivier, 1960; Person, 1917; Seidemann et al., 1998; Stewart, 1979). The age at death was estimated through the observation of degenerative processes affecting the pelvic joints, the sternal ends of the ribs, and the occlusal surface of the teeth (Brothwell, 1981; Burns, 1999; Iscan and Loth, 1986; Meindl and Lovejoy, 1985; Lovejoy, 1985; Lovejoy et al., 1985; Todd, 1921). Each individual was then assigned to one of the age classes proposed by Buikstra and Ubelaker (1994). The selected sample is composed of 18 mature adults, 13 young adults and 3 senile adults. Twelve were identified as female, 16 as male and for 6 the biological sex could not be determined. Thirteen animal samples from the same context were also analysed and identified as sheep/goat (4 NR, *Ovis vel Capra*), swine (4 NR, *Sus* sp.), lagomorph (1 NR, *Lepus* sp.), *galliformes* (2 NR) and fish (2).

Collagen extraction was carried out on femora, and when these were not available, extraction was performed on the humerus or the tibia (Supplementary Table 1), following a modified protocol adapted from Tuross (2012) and Tuross et al. (1988). Briefly, approximately 0.5 g of bone were sampled; 30 mL of EDTA 0.5 M pH 7.4 were poured into Falcon tubes with the samples. Samples were visually checked every 2–3 days and the solution was changed every 5 days for approximately 20 ± 8 days until the samples became soft and translucent. Samples were then rinsed with distilled water 14 times, with the last rinse left overnight. A pH 3 HCl solution was used for gelatinisation, by leaving the samples at 75 °C for 48 h. The solution was filtered with *Ezee Filter*™ separators and frozen. Eventually, samples were freeze-dried at −55 °C for 48 h and the collagen extracted was weighed to determine the collagen content. Approximately 1.1–1.6 mg of collagen was weighed in tin capsules and analysed at the Scottish Universities Environmental Research Centre (SUERC) laboratory using a *Thermo Scientific Delta V Advantage continuous-flow isotope ratio mass spectrometer* coupled by a ConFlo IV Universal Continuous Flow Interface with an EA *IsoLink Elemental Analyser (Thermo Scientific, Bremen)*.

Isotope data are reported as per mil (‰) using the delta (δ) notation relative to V-PDB (Vienna Pee-Dee Belemnite) for carbon and AIR (Atmospheric air) for nitrogen and V-CDT (Vienna Canyon Diablo Troilite) for sulphur.

The accuracy of the repeated measures of the check standard material is: $\delta^{13}C_{VPDB}$ ± 0.16 ‰, $\delta^{15}N_{AIR}$ ± 0.2 ‰, $\delta^{34}S_{VCTD}$ ± 0.51 ‰; the precision of the check standard, calibration standard and VWR bovine gel as replicates is: $\delta^{13}C_{VPDB}$ ± 0.08 ‰, $\delta^{15}N_{AIR}$ ± 0.2 ‰, $\delta^{34}S_{VCTD}$ ± 0.46 ‰.

Nitrogen (N%), sulphur (S%), and carbon (C%) content, collagen yield (%), C/N ratios, C/S ratios and N/S ratios were checked to assess the collagen quality (Ambrose, 1990; DeNiro, 1985; Nehlich and Richards, 2009; van Klinken, 1999).

Plotting and testing were performed in R 4.1.2 using guidelines from Vaiglova et al. (2023). Statistical outliers were identified as those exceeding 2SD of the mean value. The significance threshold for statistical tests p-value was set to $\alpha = 0.05$.

Statistical tests were applied to support the discussion of the confidence intervals (CIs) of the mean. CIs were used to estimate the range within the true population mean where the mean will likely fall rather than just the variability within the samples, thereby underlying the variations between populations' means (Moore et al., 2016). Moreover, CIs can be considered a more conservative comparison of statistical estimates for the populations' mean. In fact, as explained in Cumming 2009, when the 95 % CIs of two independent populations' means do not overlap, they correspond to statistical tests with $p \leq 0.01$. Additionally, the width of the CIs was used as a qualitative method alternative to evaluate the Power, i.e., the probability of rejecting a null hypothesis of the statistical tests, H0 (Dziak et al., 2020).

3. Results

Descriptive statistics for both animal and human samples are reported in Supplementary Table 1. Anthropological information as well as isotope values and quality criteria are reported in Supplementary Table 2. Individual 10 (adult male) was excluded from the following data analysis due to poor collagen quality criteria (Supplementary Table 2) whereas, individual 6 (young adult female) has not yielded enough collagen to perform isotopic analysis.

The animal samples are divided into herbivores, omnivores, and freshwater fish (Table 1). Herbivores δ^{13}C values range between −21.7 ‰ and −20.8 ‰ (mean and 1SD: −21.3 ± 0.4 ‰; n = 5), δ^{15}N values between 3.6 ‰ and 6.5 ‰ (mean and 1SD: 4.8 ± 1.3 ‰; n = 5) and δ^{34}S values between 2 ‰ and 11 ‰ (mean and 1SD: 7 ± 3.9 ‰; n = 5). Omnivores δ^{13}C values are between −20.7 ‰ and −18.9 ‰ (mean and 1SD: −20.0 ± 0.8 ‰; n = 6), δ^{15}N values are between 4.2 ‰ and 7.4 ‰ (mean and 1SD: 6.2 ± 1.2 ‰; n = 6) and δ^{34}S values are between 3.6 ‰ and 11.3 ‰ (mean and 1SD: 8.4 ± 2.9 ‰; n = 6). The freshwater fish group is only composed of two samples. δ^{13}C values are –23.9 ‰ (sample 45) and −21.0 ‰ (sample 47) (mean: -22.5 ‰; n = 2), δ^{15}N values are 9 ‰ (sample 47) and 9.2 ‰ (sample 45) (mean: 9.1 ‰; n = 2) and δ^{34}S values are 0.8 ‰ (sample 47) and 6.5 ‰ (sample 45) (mean: 3.7 ‰; n = 2).

Human δ^{13}C values range between −21 ‰ and −17.4 ‰ (mean and 1SD: −19.5 ± 0.7 ‰; n = 32), δ^{15}N values are between 8.7 ‰ and 10.4 ‰ (mean and 1SD: 9.6 ± 0.4 ‰; n = 32) and δ^{34}S values are between 4.1 ‰ and 10.2 ‰ (mean and 1SD: 7.6 ± 1.2 ‰; n = 32). Human and animal isotopic data are visualised in Fig. 2. Carbon isotope values across the human assemblage are indicative of a diet based on the consumption of C_3 plants. Although, since its broad range of values ($\Delta^{13}C_{max\text{-}min}$: 3.6 ‰) a minor consumption of C_4 plants could have interested at least some individuals, including samples 32 and 3 (Fig. 2**b, c**). Human samples are on average enriched by 4.1 ‰ in their δ^{15}N values compared to the animals, which is in line with a trophic level enrichment of 3–6 ‰ (Bocherens and Drucker, 2003; O'Connell et al., 2012; Schoeninger and DeNiro, 1984), suggesting the consumption of animal products (Fig. 2**a, c**). Nitrogen isotope values across the human assemblage are not widely distributed ($\Delta^{15}N_{max\text{-}min}$: 1.7 ‰) indicating a similar contribution of

Table 1
Stable carbon, nitrogen and sulphur isotope values of human individuals and animal remains from Florence San Pier Scheraggio. ND not-determined.

ID	Species	Biological Sex	Grave	Age at death	Bone sampled	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	$\delta^{34}S$ (‰)
1	*H. sapiens*	Male	1	Adult	Femur	−19.0	10.1	8.1
2	*H. sapiens*	Male	5	Young adult	Femur	−19.2	10.1	8.0
3	*H. sapiens*	NA	7	Adult	Femur	−18.3	9.6	6.4
4	*H. sapiens*	Female	1	Young adult	Femur	−21.0	9.5	6.9
5	*H. sapiens*	Male	3	Adult	Femur	−19.8	9.6	7.6
7	*H. sapiens*	Male	1	Senile adult	Femur	−19.8	9.8	7.7
8	*H. sapiens*	NA	2	Young adult	Femur	−18.8	10.1	7.8
9	*H. sapiens*	Female	7	Adult	Femur	−19.5	9.2	7.2
11	*H. sapiens*	Male	5	Young adult	Femur	−20.3	9.0	7.2
12	*H. sapiens*	Female	4	Adult	Femur	−20.3	9.3	4.1
13	*H. sapiens*	Female	1	Adult	Femur	−19.0	10.0	8.6
14	*H. sapiens*	Female	1	Young adult	Humerus	−18.6	8.7	8.5
15	*H. sapiens*	Female	4	Adult	Femur	−19.3	9.7	7.1
16	*H. sapiens*	Male	1	Adult	Femur	−19.6	9.9	8.6
17	*H. sapiens*	Female	5	Young adult	Femur	−19.4	9.7	7.4
18	*H. sapiens*	Male	5	Young adult	Femur	−19.7	9.7	6.5
19	*H. sapiens*	Male	1	Young adult	Humerus	−19.2	9.8	7.5
20	*H. sapiens*	Female	3	Adult	Femur	−19.6	10.2	8.7
21	*H. sapiens*	Male	3	Adult	Tibia	−19.4	10.4	9.4
22	*H. sapiens*	NA	2	Adult	Femur	−19.7	9.8	10.2
23	*H. sapiens*	Male	7	Adult	Femur	−19.9	9.6	6.8
24	*H. sapiens*	Male	1	Senile adult	Femur	−19.9	9.5	8.4
25	*H. sapiens*	Female	2	Young adult	Femur	−20.1	9.0	9.5
26	*H. sapiens*	Male	9	Adult	Femur	−19.7	9.5	8.0
27	*H. sapiens*	Male	3	Senile adult	Femur	−19.9	9.9	8.0
28	*H. sapiens*	Female	1	Young adult	Femur	−19.8	9.7	9.6
29	*H. sapiens*	Female	7	Young adult	Femur	−19.5	9.5	7.9
30	*H. sapiens*	Male	1	Adult	Femur	−19.9	10.3	6.3
31	*H. sapiens*	NA	5	Adult	Femur	−20.6	9.5	7.8
32	*H. sapiens*	NA	7	Adult	Femur	−17.4	9.1	5.7
33	*H. sapiens*	NA	7	Adult	Femur	−18.9	9.2	6.3
34	*H. sapiens*	Male	2	Young adult	Femur	−20.3	9.6	6.7
35	*Ovis* sp.	NA	2	NA	phalanx II	−20.8	6.5	6.4
36	*Sus* sp.	NA	2	NA	ulna	−20.2	5.9	11.3
37	*Sus* sp.	NA	2	NA	ulna	−18.9	7.3	8.8
38	*Ovis* sp.	NA	2	NA	tibia	−21.3	4.5	2.0
39	*Ovis* sp.	NA	2	NA	scapula	−21.0	5.8	11.0
40	*Aves* sp.	NA	5	NA	humerus	−20.3	7.4	9.6
41	*Sus* sp.	NA	5	NA	humerus	−20.7	5.5	10.8
42	*Lepus* sp.	NA	5	NA	radius	−21.6	3.6	10.9
43	*Ovis* sp.	NA	2	NA	radius	−21.7	3.6	4.8
44	*Sus* sp.	NA	4	NA	tibia	−20.7	4.2	3.6
45	*Pisces*	NA	4	NA	mandible	−23.9	9.2	6.5
46	*Galliformes*	NA	5	NA	humerus	−18.9	6.8	6.5
47	*Pisces*	NA	NA	NA	unidentifiable	−21.0	9.0	0.8

protein sources. One individual (sample 14) was identified as an outlier (i.e., exceeding 2SD from the mean) due to its $\delta^{15}N$ value (8.8 ‰), which may suggest a lower consumption of animal products. Sulphur isotope values are rather dispersed ($\Delta^{34}S_{max-min}$: 6.1 ‰), with two individuals also identified as outliers (samples 12 and 22, Fig. 2**b**, **c**). This variation might indicate mobility from a different location (Varalli et al., 2016; Vika, 2009). However, it is important to note that these individuals fall within the overall range of faunal $\delta^{34}S$ values. Statistical tests were used to assess possible differences in the isotopic values based on age at death and biological sex (Supplementary Table 3). The $\delta^{34}S$ values for freshwater fish are partially consistent with the ones reported by Cortecci et al. (2002) for the pristine (i.e., non-polluted) section of the modern Arno River (−10.6 to +3.9 ‰). It seems that values increase along the river's course (up to 16.8 ‰). However, this increase was also attributed to anthropogenic pollution, so caution is needed when interpreting these values.

4. Discussion

Human isotopic values indicate a diet predominantly based on C_3 plants and animal products consumption, with no evidence of marine fish across most samples (Fig. 2**a, b, c** and Table 1 **and** Supplementary Table 1). $\delta^{13}C$ values for certain of the human samples (i.e., 3, 14, and 32) suggest a minor influence of C_4 plants. This aligns with the available archaeobotanical record for the area, which is also composed of C_4 cereals (Buonincontri et al., 2017). We have tentatively suggested that humans buried at San Pier Scheraggio may have held a privileged position. C_4 cereals (e.g., millet) were generally thought to be consumed mostly by the lower class or peasants (Montanari, 2000) often in the form of soups. However, the most ancient Tuscan cookbooks indicate that it was common to dignify "poor" ingredients (i.e., suitable for higher social classes) such as millet (C_4 plant) combining them with "precious" ingredients (i.e., spices and herbs) (Montanari, 2000; Zambrini, 1863).

Given the observed $\delta^{15}N$ offset between fish and human values ($\Delta^{15}N_{humans-fish}$: 0.5 ‰), there is no clear evidence that freshwater fish was a major component of the diet of these individuals. Moreover, the limited number of fish specimens limits our ability to evaluate the contribution of these foodstuffs to the human diet. However, factors such as the Lent imposed by the Church, the proximity to the Arno River, and the presence of fish remains within the tombs suggest the ready availability of this protein source. Thus, at this stage, we cannot rule out its consumption entirely. Similarly, $\delta^{34}S$ results indicate a lack of marine fish consumption. Which is expected considering the distance from the coast of Florence (ca. 80 km) and also that the flourishing trade of marine fish, particularly herrings from the Atlantic, known to have

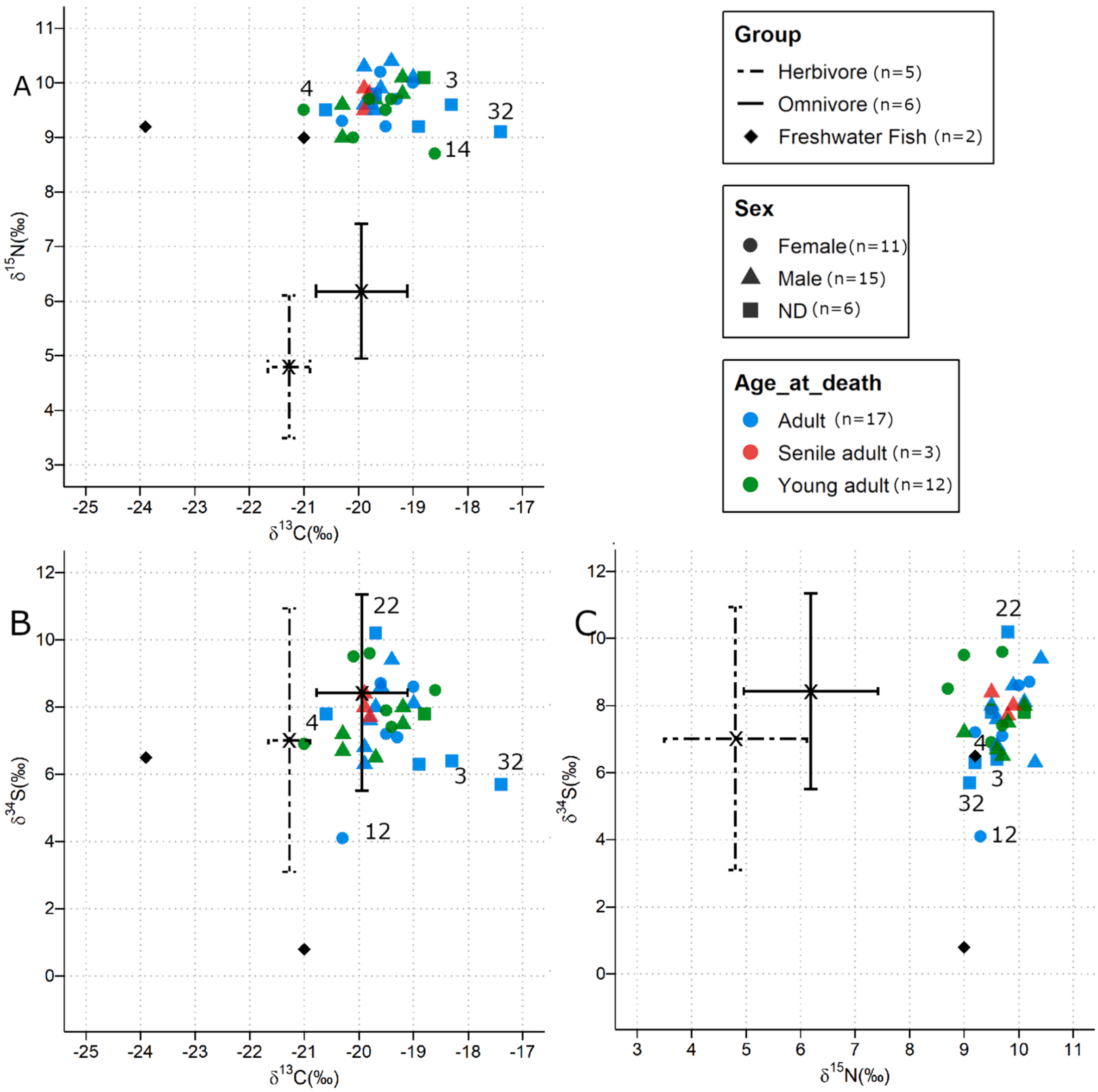

Fig. 2. Stable carbon, nitrogen and sulphur isotope values of human individuals (n = 32) and animal (n = 13) remains from Florence San Pier Scheraggio. A) bi-plot of carbon vs nitrogen isotope values; B) bi-plot of carbon vs sulphur isotope values; C) bi-plot of nitrogen vs sulphur isotope values. Animals are grouped into herbivores and omnivores and plotted with their mean value ± 1SD, freshwater fish are plotted individually. Humans are divided into biological sex and age at death and plotted individually.

begun in other parts of Europe around 1000 CE, will only come to Italy during the XIV century CE (Ervynck et al., 2004; Nigro, 1997). We therefore note that the lack of isotopic evidence of fish consumption contrasts with the Lent imposed by the Church, suggesting that this phenomenon was less strict than depicted in historical sources. However, it should be noted that Lent could be observed in different ways, such as with the simple abstinence from terrestrial meat consumption and the consumption of animal secondary products.

The relatively high δ^{15}N values of humans compared to terrestrial animals ($\Delta^{15}N_{\text{humans-terrestrial animals}}$: 4 ‰) suggest that terrestrial animal products played a significant role in their diet. This is also suggested by the comparison with other sites from the Middle Ages carried out in the next paragraph. In the early High Middle Ages, these products were an expensive resource, and their high consumption could indicate wealth. This aligns with the fact that these individuals were buried in the cloister arcade of the church, which was traditionally considered a privileged burial position. One individual (14) was identified as an outlier considering their δ^{15}N collagen value, which might indicate a lower contribution of animal products compared to the others. Stable carbon, nitrogen, and sulphur isotope values suggest a lack of statistically significant differences according to biological sex (p-values = 0.576, Supplementary Table 3). This contrasts with historical sources, which suggest that women were controlled in the quality and quantity of food consumed by the Christian doctrine, according to which an excessive consumption of food, in particular meat, was linked to carnal desire (Adamson, 2004; Bynum, 1988; Pearson, 1997; Stewart, 2017). However, the p-value of the *t*-test applied to males and females for their δ^{15}N values (p-value = 0.097, Supplementary Table 3) and the confidence intervals (CIs) obtained from the values of the biological sex do not support such an assumption (Supplementary Table 1). These results are consistent with studies from the literature for mediaeval Tuscany (Buonincontri et al., 2017; Scorrano et al., 2014) and broader mediaeval Italy (Baldoni et al., 2019; Ciaffi et al., 2015; Reitsema and Vercellotti, 2012). Specifically, Reitsema and Vercellotti (2012) found no differences in diet according to biological sex across high-status individuals, while differences were found in the low-status group. This is in contrast with what is observed at Colonna (Baldoni et al., 2016). We also did not observe statistically significant differences in the means in accordance to the age at death of the individuals (young vs adults δ^{13}C p-value = 0.688, δ^{15}N p-value = 0.690, δ^{34}S p-value = 0.190, Supplementary Table 3). This is consistent with observations from Scorrano et al. (2014) at Cosa (GR) and Baldoni et al. (2019) at Leopoli-Cencelle (VT). The similar dietary patterns in relation to age at death and biological sex suggest that in Middle Ages Florence, or at least in our assemblage, access to high-quality food resources was relatively equal, even for the section of the population that did not directly contribute to the economy of the group (i.e., elderly). This could imply either a great abundance of quality resources or rather to the social equality intrinsic in the population of Florence.

When we take into account the δ^{34}S distribution of the human

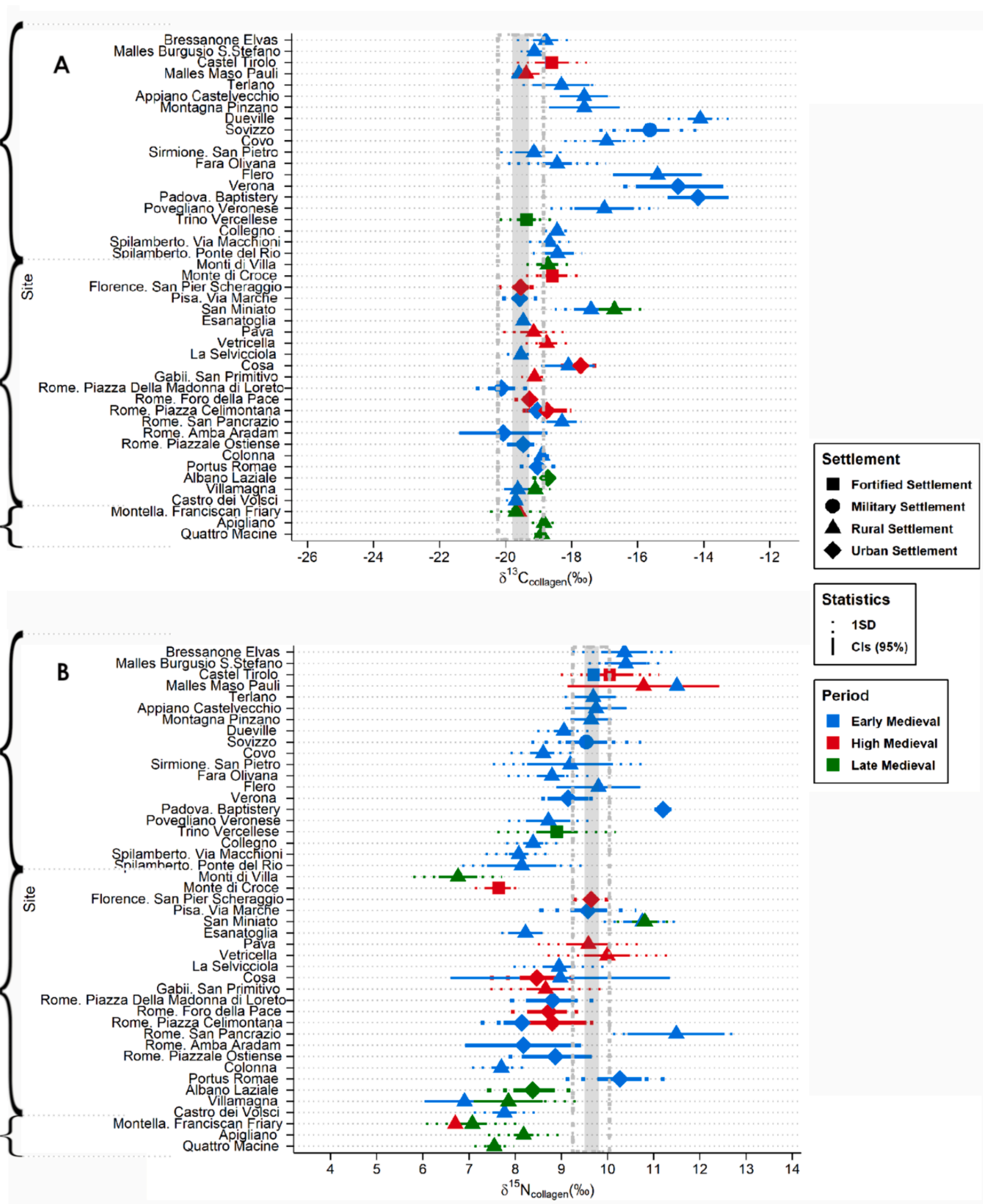

Fig. 3. Plots of mean ± CIs (95 %) (line) and mean ± 1SD (dotted line) carbon (a) and nitrogen (b) values for humans from mediaeval Italy (from literature, for the number of individuals per site see **Supplementary Tables 3–6**) and Florence San Pier Scheraggio (this study). The mean values are reported with their confidence intervals. The sites are ordered in relation to the latitude and are divided by period (colour) and by type of settlement (shape). The grey band represents Florence San Pier Scheraggio's CIs (95 %).

samples (mean ± 2SD), samples 12 and 22 are found to be outliers. This seems to suggest that the two individuals consumed food with a distinct origin compared to the other individuals buried at San Pier Scheraggio (Rand et al., 2021; Varalli et al., 2016; Vika, 2009). This is interesting considering that Florence in that period was a flourishing city with important commercial routes, which might have resulted in a heterogeneous population. However, it is important to note that all individuals fall within the δ^{34}S range of terrestrial animals, suggesting caution with the interpretation.

4.1. Comparison with isotopic data in mediaeval Italy

We compared our individuals with those previously published for mediaeval Italy using the open-access database "Compendium Isotoporum Medii Aevi" (CIMA) (Cocozza et al. 2022) (refer to Supplementary Table 4, 5 for references for each site) with the aim to characterise our data in a broader context. We excluded sulphur from this comparative analysis since, to our knowledge, there is only one other mediaeval study using stable sulphur isotope analysis, which focuses on a site that is distant from the focus of this paper (Fiorin et al., 2021). Firstly, we explored the faunal assemblage from the sites (Supplementary Table 6) to observe the distribution of stable carbon and nitrogen isotope values and acknowledge possible differences in the animal husbandry practices and environmental and climatic phenomena (see **Supporting Information**).

When we explore the human stable isotope values, we observe that Florence San Pier Scheraggio exhibits among the lowest mean δ^{13}C value and the highest mean δ^{15}N value of the entire Peninsula (Fig. 3**a, b**). In Tuscany, Early Medieval Pisa via Marche exhibits δ^{13}C values similar to those of Florence San Pier Scheraggio, despite differences in their faunal baselines (**Supporting Information**). In contrast, the other sites from Tuscany (San Miniato, Cosa, Monte di Croce, Monti di Villa, Pava, Vetricella) have more ^{13}C-enriched δ^{13}C values, suggesting various degrees of consumption of C_4 plants and/or of marine resources particularly in the coastal sites (i.e., Cosa and Vetricella). Regarding δ^{15}N in Tuscany, only San Miniato and Pava display enriched δ^{15}N values similar to those observed at San Pier Scheraggio. San Miniato might be influenced by marine resource consumption, considering the enriched δ^{13}C values, while Pava, on the other hand, might have reflected a high contribution of animal products. Intriguingly, the fortified High Middle Ages settlement of Monte di Croce, located at ca. 15 km from Florence, shows lower δ^{15}N values compared to San Pier Scheraggio, potentially due to lesser consumption of animal products, as suggested by the authors (Buonincontri et al; 2017). However, this could be linked to the fauna from Monte di Croce that shows slightly lower δ^{15}N values (Supplementary Table 6, δ^{15}N $p = 0.05$). The authors suggest a diet predominantly based on the consumption of mixed cereals, including some of the C_4 type. The difference from San Pier Scheraggio could be tentatively linked to a shift from a subsistence strategy to a market economy; thereby, Florence would have had access to more valuable foodstuffs compared to smaller nearby settlements. However, it is not possible to rule out the possibility that humans from Monte di Croce and San Pier Scheraggio would have consumed a similar proportion of animal products, although exhibiting different δ^{15}N values in their bone collagen since the animals from Monte di Croce show lower δ^{15}N values compared to those from San Pier Scheraggio. This highlights the need for more studies on the effect that the market economy had on people from urban settlements. As for the role of C_4 cereals, the different degree of consumption of these plants among the Tuscans, considering their availability, also in Florence, and the social implications, puts Florence San Pier Scheraggio in a different position with respect to the other sites. We tentatively suggest that this could be due to a different wealth within the population.

It is not surprising to observe differences in δ^{13}C values (Supplementary Table 3, Fig. 3**a**) between Florence San Pier Scheraggio and the majority of northern Italian sites. These differences are mainly due to the higher consumption of C_4 plants in the northeast, which is typical of those regions for that period (e.g., Iacumin et al., 2014) (Fig. 3**a**). Northernmost sites do not seem to be influenced by a high contribution of C_4 plants in their diet, which is not surprising considering that these plants are usually cultivated at lower altitudes (Paladin et al., 2020). Some of these sites (Bressanone Elvas, Malles Burgusio S. Stefano, most of Malles Maso Puli, Montagna Pinzano) display enriched δ^{15}N values supporting an elevated consumption of animal products (Paladin et al., 2020), although it should be acknowledged that the range of CIs is relatively broad both in humans and in the baseline warrants cautious interpretation. The urban sites of Padua and Verona show high δ^{15}N values, suggesting a significant intake of animal products (Laffranchi et al., 2020; Marinato, 2017). However, we note that the faunal remains from the region have higher δ^{15}N values than those from other regions; therefore, we interpret this evidence with caution.

As for other sites from Central Italy, excluding Tuscany, only two urban sites exhibit statistically higher values in δ^{15}N. These are Rome San Pancrazio, where the authors have argued that the elevated δ^{15}N is indicative of freshwater fish consumption (Varano et al., 2020), and *Portus Romae*, where consumption of fish was also suggested (O'Connell et al., 2019) (Fig. 3**b**). The δ^{13}C values from most sites in Central and Southern Italy are statistically similar, reflecting a predominant diet of C_3 cereals in these regions.

The comparison with the other mediaeval Italian sites has allowed a better contextualisation of the data from Florence San Pier Scheraggio. Compared to other sites, the people buried at San Pier Scheraggio show a diet relatively high in terrestrial animal products and low in C_4 plants, which places the site in a different position compared to the majority of other contemporary sites in Tuscany and Italy in general. Their dietary habits likely reflect the social position of the individuals deposed, given also the transitional period in which the site was used. In light of the differences between San Pier Scheraggio and sites with a clear evidence of fish consumption (Rome San Pancrazio, *Portus Romae*), there is no substantial evidence of significant fish consumption at San Pier Scheraggio. However, a minor contribution of freshwater resources cannot be entirely excluded, particularly given the limited number of specimens available for analysis. Nonetheless, the lack of significant consumption of these resources is in line with what is observed at other Italian mediaeval sites. Suggesting that, in a first period, Lent was probably more rigorously respected by the clergy (Reitsema and Vercellotti, 2012).

5. Conclusions

Our study has allowed us to investigate the dietary habits of a high mediaeval assemblage from the cloister arcades of San Pier Scheraggio's church (Florence, Italy). The diet of the individuals examined predominantly relied on C_3 plants with a significant intake of animal products, considering other mediaeval Italian sites. The comparison with proximal smaller settlements for the same period (i.e., Monte di Croce, ca. 15 km NE) supports the hypothesis that smaller settlements supplied valuable food items for urban settlements. Our isotopic data does not suggest any relevant input of fish in the dietary habits of the assemblage. However, given the importance of Lent and the proximity of the Arno River, we cannot exclude the consumption of freshwater resources completely. We observed a relatively higher contribution of C_4 plants in the diet of a few individuals; however, the majority of our assemblage is mainly consuming C_3 plants, which puts San Pier Scheraggio in a different position compared to some of the rural sites from Tuscany. Considering the stable sulphur isotope value, it is possible that at least two individuals consumed food sources with a different origin compared to the rest of the assemblage, attesting a certain variability in the group buried at San Pier Scheraggio. The absence of significant statistical differences in the isotope values according to age at death and the biological sex of the individuals indicates a fairly homogenous diet. It could reflect a general availability of quality resources, potentially indicating economic power or social equality intrinsic to Florence individuals. Since it is most likely that the individuals from San Pier Scheraggio were buried in a privileged position, it is important to contextualise any interpretations within this framework. To gain a fuller understanding of Florence dietary habits, we recommend directing future research towards lower socioeconomic groups within the city and neighbouring rural archaeological sites. Such investigations would strengthen the hypothesis of a prevalent market economy during this historical period, which we suggest for the case of San Pier Scheraggio. Additional studies should be addressed to clarify the contribution of freshwater fish to the diet of mediaeval Florence, for example, by applying the stable carbon and nitrogen analysis of collagen amino acids. This could help underline when Lent began to be an important part of people's lives rather than a simple imposition. Finally, $^{87}Sr/^{86}Sr$ and $\delta^{18}O$ isotopes measured in enamel apatite could better characterise possible mobility within the group and help to further explore cultural phenomena.

6. Lay Summary

The Uffizi Complex in Florence is one of the best known and significant cultural venues in the world. What is less known is that under the complex lies the prominent church of San Pier Scheraggio. The church, built between the XI and XII centuries CE was part of a larger complex owned by the Ubertis, a prominent family of the *Ghibellini* party. The recent renovations (2015) of the Uffizi complex have revealed 9 tombs dated to the Middle Ages, which provided one of the few skeletal series available for this period in Florence. The skeletal sample provides the opportunity to investigate past diet and mobility via stable carbon, nitrogen, and sulphur isotopes. The result obtained reveal that people buried in San Pier Scheraggio have a diet composed of C_3 plants (e.g., wheat, barley, and emmer) with a relatively high consumption of animal products. A comparison of the results obtained with the relevant literature has shown interesting differences for the area of Florence and might provide insight into the complexity of food practices in mediaeval Italy.

7. Declaration of generative AI

During the revision of this work the authors used ChatGPT 4 in order to improve the readability and language of the manuscript. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

CRediT authorship contribution statement

Matteo Giaccari: Writing – original draft, Methodology, Investigation, Formal analysis, Data curation. **Silvia Soncin:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Data curation. **Alessandro Riga:** Writing – review & editing, Investigation. **Martina Di Matteo:** Writing – review & editing, Investigation. **Paolo Lelli:** Writing – review & editing, Resources. **Maura Pellegrini:** Writing – review & editing, Conceptualization. **Mary Anne Tafuri:** Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

The data supporting the findings of this study are available within the article and/or its supplementary materials

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jasrep.2024.104783.

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