

Article

Dietary Reconstruction of Migrant Populations in the Core Region of Early China

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Abstract

This study focuses on 91 human individuals from the Western Zhou period excavated from the Jucun cemetery in Jiang County, southern Shanxi Province, and examines their dietary structure and its changes within the context of population movements in early China. Stable carbon and nitrogen isotope analysis was employed, combined with archaeological phase divisions, to compare dietary patterns across different periods. The results show that the Jucun population exhibits a diet dominated by C₄ resources, with a mean $\delta^{13}\text{C}$ value of $-8.0 \pm 0.7\text{‰}$ and a mean $\delta^{15}\text{N}$ value of $8.6 \pm 0.9\text{‰}$, indicating a relatively low level of animal protein intake. Diachronic analysis indicates that $\delta^{13}\text{C}$ values remain generally stable throughout the Western Zhou period, whereas $\delta^{15}\text{N}$ values show a decreasing trend. Regional comparison further shows that populations of different origins all fall within the isotopic range characterized by millet-based agriculture in southern Shanxi. Overall, the dietary structure of this population exhibits a convergence toward an agriculture-based pattern centered on millet. This study provides bioarchaeological evidence for subsistence transformation and cultural integration among mobile populations in the Central Plains during the Western Zhou period.

Keywords: stable isotope analysis; Western Zhou; dietary structure; subsistence economy; population mobility

1. Introduction

The Western Zhou period (c. 1046–771 BCE) marks a critical stage in the formation of an early territorial state in China and the gradual development of Huaxia identity (Hsu, 1965; Kern, 2009; Qu, 2021). The middle Yellow River region, particularly southern Shanxi, functioned both as a strategic frontier for Zhou political expansion and as a core area of millet-based agricultural production, supported by a long-established dry farming system.

At the same time, large-scale population movements during the Shang–Zhou transition substantially reshaped the demographic landscape of the Central Plains. Groups broadly referred to in historical texts as the “Rong” and “Di,” often regarded as non-Huaxia populations from the northern highlands, migrated southward into the plains of southern Shanxi. There, they coexisted and interacted with populations affiliated with the Zhou polity, forming a region characterized by intensive intergroup contact. This historical context provides an important framework for investigating processes of population interaction, integration, and the formation of early Chinese cultural identity (Cao, 2022; Y. Yang, 2023).



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Dietary practices and subsistence strategies constitute fundamental material expressions of cultural identity, survival strategies, and social organization, and are often among the earliest domains in which intergroup interaction and integration occur (Christine, 2017). For populations such as the Rong and Di who migrated into the core regions of the Central Plains, a key question concerns how their dietary structure and subsistence systems were reconfigured within new ecological and socio-political settings. Stable carbon and nitrogen isotope analysis provides a well-established method for quantitatively reconstructing ancient diets and subsistence practices, offering a robust empirical approach to addressing these issues.

Stable carbon and nitrogen isotope analysis is based on the isotopic transfer between food and human tissues. Differences in $\delta^{13}\text{C}$ values between C_3 and C_4 plants reflect the consumption of different types of plant resources, while the stepwise enrichment of $\delta^{15}\text{N}$ values along the food chain is used to indicate trophic level and the relative contribution of animal protein (Ambrose, 1993; Bocherens & Drucker, 2003; Deniro & Epstein, 1981; Katzenberg, 2007; Lee-Thorp, 2008). In addition, marine and terrestrial food chains exhibit distinct stable isotope compositions, and these differences are transferred to human consumers. Therefore, the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of human bone collagen can reflect the relative contributions of marine and terrestrial foods in prehistoric diets. The consumption of freshwater aquatic resources may also influence human stable isotope values and lead to elevated $\delta^{15}\text{N}$ values, although their isotopic characteristics generally differ from those of marine foods (Chisholm et al., 1982; Schoeninger & Deniro, 1984; Hobson & Welch, 1992; Vander Zanden et al., 1997). Overall, the combined analysis of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values enables the quantitative reconstruction of dietary structure and subsistence practices in past populations.

Previous isotopic studies of human remains from the Western Zhou period in southern Shanxi have produced important insights, among which research on the Hengshui cemetery in Jiang County is particularly representative. These studies have demonstrated pronounced dietary stratification within the feudal societies of the Western Zhou, revealing a strong correlation between individual dietary intake and hierarchical social status, and thus providing critical evidence for understanding the social organization of Zhou polities (Hou et al., 2022; Sun, 2019). However, existing interpretations have largely been framed within the context of Zhou ritual and hierarchical systems centered on the Central Plains. As a result, the populations represented at Hengshui—generally identified as Di groups—have not been systematically examined from the perspective of migration. In particular, there remains a lack of analytical frameworks that address dietary adaptation and subsistence restructuring among migrant populations.

The Jucun (睢村) cemetery in southern Shanxi represents an important archaeological assemblage with cultural characteristics closely comparable to those of the Hengshui cemetery. Current archaeological studies suggest that the majority of the population in Jucun and Hengshui cemetery belonged to the Di people who migrated from the northern mountains to southern Shanxi during the Shang (c. 1600–1046 BCE) and Zhou (c. 1046–256 BCE) dynasties, which is an ideal object for studying the dietary adaptation of the migrating Di people (Su, 2025; Xie, 2019; Y. Yang, 2023).

Against this background, this study analyzes human skeletal remains from the Jucun cemetery using stable carbon and nitrogen isotope analysis, with three primary objectives: (1) to reconstruct the overall dietary structure and subsistence patterns of the Jucun population; (2) to examine diachronic changes in dietary practices during the Western Zhou period; and (3) to contextualize these results through comparative isotopic analysis with contemporaneous populations in southern Shanxi, in order to evaluate the dietary strategies of migrant Di groups. Through this approach, the study aims to provide micro-scale ev-

idence for subsistence restructuring and cultural integration among migrant populations in the core region of early China.

2. Site Background

The Jucun cemetery is located in Jiang County, Yuncheng City, southern Shanxi Province, approximately 5 km west of the county seat and about 20 km from the Hengshui cemetery (Figure 1). Situated on the southern Shanxi plain, the site lies south of the Zhongtiao Mountains and is bordered by the Jiang Mountains to the northwest, with a seasonal river to the west. It represents a large public cemetery used continuously from the early to late Western Zhou period. The site was discovered in 2011 following looting activities and was subsequently excavated between 2013 and 2018 by the Shanxi Provincial Institute of Archaeology and related institutions. A total of 854 burials were identified, yielding more than 11,000 grave goods, including bronzes, ceramics, jade artifacts, bone tools, shell objects, and lacquerware (J. Wang, 2016). As the full excavation report has not yet been formally published, current interpretations rely primarily on preliminary and interim research results.



Figure 1. Location of the Jucun cemetery in Shanxi Province, China.

Based on the available data, the cemetery is characterized predominantly by rectangular vertical shaft pit graves oriented east–west, with extended supine burials as the most common funerary practice, indicating a degree of standardization in mortuary behavior (J. Wang, 2016). Previous studies have shown that the Jucun population exhibits a high degree of similarity to contemporaneous populations at Hengshui in terms of physical anthropological characteristics and demographic structure (Han & Gao, 2025; H. Zhao, 2018). More importantly, analyses of burial typology, artifact assemblages, and cultural features consistently suggest that the primary population at Jucun consists of Di groups who migrated from the northern highlands into southern Shanxi during the early to middle Western Zhou period, sharing close cultural affinities with the Hengshui cemetery (Y. Yang, 2023; Su, 2025). This interpretation provides a critical foundation for the present study, which approaches dietary patterns from the perspective of migrant populations.

3. Materials and Methods

A total of 91 individuals from the Western Zhou period excavated at the Jucun cemetery were selected for stable isotope analysis. Long bone fragments were sampled, representing approximately 10% of the total excavated population, and were selected using a simple random sampling strategy. Sex and age at death were estimated based on the osteological assessments conducted by Zhao at Jilin University (H. Zhao, 2018), following standard physical anthropological methods (Zhu, 2004). Overall skeletal preservation at

the Jucun cemetery is good. Of the 91 individuals, sex could be determined for 75 individuals (33 males and 42 females or probable females), while the remaining 16 individuals were classified as indeterminate.

Collagen was extracted at the Bioarchaeology Laboratory of Jilin University following the protocol outlined by Richards and Hedges (Richards & Hedges, 1999). Bones (~2 g) were cleaned by sonication and then demineralized in a 0.5-M HCl solution at below 5 °C until the bones were soft and bubble-free. The HCl solution was changed every 2–3 days. To remove humic acid, the samples were rinsed with deionized water until they became neutral and then soaked in 0.125-M NaOH at room temperature for 20 h. After rinsing with deionized water, the samples were gelatinized in a pH3 HCl solution at 70 °C for 48 h. Finally, bone collagen was obtained by lyophilization after concentration and freezing.

Collagen samples were measured using an IsoPrime-100 IRMS coupled with an Elementar PyroCube elemental analyser (Elementar, Langenselbold, Germany) at the Test Center of the Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences. Sulfanilamide was used as the standard for measuring carbon and nitrogen content. IAEA-N-1 ($\delta^{15}\text{N} = +0.4\text{‰}$) and USGS24 ($\delta^{13}\text{C} = -16.1\text{‰}$) were used to normalize N_2 (AIR as standard) and CO_2 (VPDB as standard), respectively, using reference gases stored in steel cylinders. After every ten samples, an in-house collagen standard ($\delta^{13}\text{C} = -14.7 \pm 0.1\text{‰}$, $\delta^{15}\text{N} = 6.9 \pm 0.2\text{‰}$) was analysed to monitor analytical accuracy. The analytical precision for $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ was $\pm 0.2\text{‰}$. Each sample was measured in duplicate; the mean value was used, and a standard deviation of less than $\pm 0.1\text{‰}$ was ensured. Results were expressed as $\delta^{13}\text{C}$ (relative to VPDB) and $\delta^{15}\text{N}$ (relative to AIR) (Table 1 and Figure 2). SPSS 25 and Origin 2025b were used for statistical analysis.

Table 1. Basic information and stable isotope results of human individuals from the Jucun cemetery.

No.	Lab. ID	Burial Context	Period	Sex	Age (Years)	Skeletal Element	C (%)	N (%)	C/N	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)
1	SJJ94	M1001	E	M	40–45	Fibula	32.5	11.5	3.3	−7.6	8.7
2	SJJ97	M1002	U	F	25±	Humerus	39.1	14	3.3	−7.3	7.2
3	SJJ96	M1003	M	F	20±	Ulna	34	12.1	3.3	−7.2	7.7
4	SJJ98	M1004	M	M	40±	Fibula	37.5	13.3	3.3	−8.2	9.4
5	SJJ86	M1010	M	F	17–19	Fibula	38.4	13.7	3.3	−8	10
6	SJJ90	M1011	M	F	25±	Radius	18.3	6.7	3.2	−9.2	7.3
7	SJJ72	M1017:2	L	nan	8–9	Ulna	20.5	7.1	3.4	−8.2	7.1
8	SJJ85	M1022:2	M	F	20–25	Fibula	39.6	14.0	3.3	−7.6	7.6
9	SJJ71	M1024	U	F	30–35	Fibula	35.5	12.7	3.3	−6.6	8.2
10	SJJ101	M1042	M	M	40–45	Ulna	16.4	6.4	3.1	−8	8.5
11	SJJ62	M1044	M	F	30±	Ulna	21.4	7.6	3.3	−8.1	8.8
12	SJJ87	M1047	M	nan	25±	Fibula	41.1	14.7	3.3	−7.6	8.1
13	SJJ63	M1053	M	F	45±	Ulna	41.5	14.8	3.3	−7.3	8.5
14	SJJ59	M1054	U	M	30±	Fibula	25.2	9.3	3.2	−7.7	7.7
15	SJJ91	M1057	U	M	25–30	Fibula	18.8	6.8	3.2	−8.2	8.7
16	SJJ92	M1069	U	F	25–30	Fibula	36.7	13.1	3.3	−7.8	8.1
17	SJJ93	M1070	M	F	45–50	Fibula	31	11.6	3.1	−8	9.1
18	SJJ95	M1071	U	M	40–45	Fibula	24.7	9.6	3	−7.1	8.7
19	SJJ99	M1074	L	F	17–19	Ulna	37.3	13.2	3.3	−7.8	8
20	SJJ100	M1077	U	F	15–16	Fibula	29.8	11.1	3.1	−7.4	7.9
21	SJJ57	M1078	U	nan	12–15	Fibula	38.5	13.7	3.3	−7.1	7.5
22	SJJ74	M1079	U	nan	Adult	Fibula	35.2	12.8	3.2	−7.3	7.8
23	SJJ50	M1080	M	nan	8–9	Fibula	29.9	10.5	3.3	−7.6	8
24	SJJ102	M1082	U	M	35±	Fibula	25.1	8.8	3.3	−6.3	8.2
25	SJJ66	M1084	M	F	20±	Ulna	29.4	11.2	3.1	−8.3	8.5

Table 1. Cont.

No.	Lab. ID	Burial Context	Period	Sex	Age (Years)	Skeletal Element	C (%)	N (%)	C/N	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)
26	SJJ76	M1085	M	nan	15±	Fibula	41.2	14.5	3.3	−8.8	8
27	SJJ68	M1192	M	F	35±	Radius	25.8	9.4	3.2	−7.8	9
28	SJJ61	M1264	E	F	50±	Femur	35.6	12.7	3.3	−7.4	8.7
29	SJJ73	M1288	M	F	35–40	Tibia	37.3	13.1	3.3	−7.8	8.3
30	SJJ64	M1291	E	F	30±	Humerus	29	10.4	3.2	−8	7.5
31	SJJ89	M1300	M	F	20±	Fibula	35.2	12.6	3.3	−6.9	7.5
32	SJJ60	M1301	M	F	35±	Fibula	39.8	14.6	3.2	−7.4	7.7
33	SJJ65	M1322	E	M	Adult	Fibula	43.8	15.6	3.3	−8.8	9.9
34	SJJ67	M1334	M	F	25–30	Fibula	27.6	9.7	3.3	−7.2	7
35	SJJ49	M1358	M	nan	40±	Ulna	42.1	15	3.3	−8.1	9.5
36	SJJ55	M1370	U	M	30±	Fibula	17.2	6.2	3.2	−7.2	7.8
37	SJJ51	M1383	U	M	45–50	Ulna	18.8	6.6	3.3	−7.6	7.9
38	SJJ54	M1388	U	F	15–20	Fibula	35.4	13.9	3	−8.6	7.7
39	SJJ56	M1398	E	M	40–45	Fibula	29.4	10.4	3.3	−8	9.8
40	SJJ75	M1399	U	F	20–25	Fibula	41.7	14.9	3.3	−7.9	7.4
41	SJJ77	M1420	U	M	40±	Fibula	32	11.4	3.3	−7.7	8.9
42	SJJ53	M1421	M	M	30±	Tibia	21.7	7.6	3.3	−8.2	9.6
43	SJJ78	M1432	U	F	35–40	Fibula	34.7	12.3	3.3	−7.9	8.5
44	SJJ88	M1434	U	M	20–25	Fibula	25.2	9.1	3.2	−7.3	7.8
45	SJJ58	M1438	M	nan	Adult	Femur	25.4	9.3	3.2	−8.9	9.9
46	SJJ79	M1441	U	M	45±	Fibula	34.3	12.3	3.2	−7.9	8.6
47	SJJ16	M2001	U	F	Adult	Fibula	35.3	12.6	3.3	−8.8	9.3
48	SJJ24	M2002:1	U	nan	nan	Humerus	32.1	11.2	3.3	−9	9.7
49	SJJ15	M2018	U	M	20–25	Fibula	42	15.2	3.2	−8.2	8.4
50	SJJ43	M2019	U	F	14–16	Fibula	38.9	13.8	3.3	−7.9	7.6
51	SJJ40	M2022	U	nan	35–40	Femur	19.9	8.1	2.9	−8	10
52	SJJ25	M2025	M	F	30–35	Ulna	27.9	10.6	3.1	−8.8	8.2
53	SJJ21	M2028	E	F	35±	Radius	40.4	14.5	3.3	−8.6	9.1
54	SJJ13	M2031:2	U	F	20±	Fibula	33.6	11.9	3.3	−9	9.5
55	SJJ26	M2032	E	M	25±	Ulna	40.1	14.1	3.3	−7.7	8.4
56	SJJ18	M2040	U	M	35–40	Ulna	17.1	5.9	3.4	−8.3	10.2
57	SJJ17	M2041	M	F	40–45	Ulna	34	12.1	3.3	−8.2	8.2
58	SJJ11	M2046	U	F	20±	Ulna	16.5	5.7	3.4	−9	7.8
59	SJJ47	M2048	U	nan	45±	Ulna	39.9	14	3.3	−8.2	9.4
60	SJJ22	M2053	U	F	35±	Ulna	20.3	6.9	3.4	−9.8	9
61	SJJ23	M2054	U	nan	7–9	Femur	36.7	13.6	3.2	−7.1	8.5
62	SJJ44	M2068	E	F	35–40	Fibula	33.9	12	3.3	−7.9	9.2
63	SJJ36	M2072	M	F	40±	Fibula	41	14.6	3.3	−7.8	7.8
64	SJJ30	M2073	E	M	25–30	Humerus	40.9	14.4	3.3	−8.3	9.9
65	SJJ8	M2077	M	F	35±	Fibula	30.4	10.8	3.3	−7.7	8.7
66	SJJ1	M2082	M	nan	10–15	Fibula	18.9	6.3	3.5	−9.5	7.7
67	SJJ7	M2087	U	nan	25±	Fibula	39.1	13.8	3.3	−7	7.8
68	SJJ42	M2088	M	M	35–40	Femur	41	14.7	3.3	−7.2	8.8
69	SJJ5	M2100	U	nan	10±	Fibula	34.2	11.9	3.3	−7.9	7.8
70	SJJ9	M2113	U	M	Adult	Femur	37.5	13.2	3.3	−7.9	10.7
71	SJJ27	M2114	U	F	30±	Fibula	30.6	10.9	3.3	−8.2	8.9
72	SJJ37	M2115	U	M	35±	Fibula	37.1	13.3	3.3	−8.3	9.9
73	SJJ46	M2116	U	M	40–45	Fibula	27.3	9.5	3.4	−7.3	8
74	SJJ31	M2134	E	M	45–50	Femur	22.4	8.2	3.2	−8.8	10
75	SJJ32	M2140	U	M	30±	Ulna	37.9	13.4	3.3	−8.1	8.8
76	SJJ6	M2144	U	M	25±	Fibula	36	12.3	3.4	−8.8	9.3
77	SJJ35	M2150	U	nan	20±	Fibula	33.5	11.9	3.3	−7.5	8
78	SJJ29	M2181	U	M	20–25	Fibula	42.5	15.4	3.2	−7.3	7.6

Table 1. *Cont.*

No.	Lab. ID	Burial Context	Period	Sex	Age (Years)	Skeletal Element	C (%)	N (%)	C/N	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)
79	SJJ69	M2203	U	F	15–20	Fibula	30.2	10.6	3.3	−8.1	8.2
80	SJJ20	M2222	U	M	35–40	Fibula	24.2	8.5	3.3	−7.4	9.4
81	SJJ70	M2226	U	M	35–40	Ulna	28.2	10	3.3	−8	9.4
82	SJJ82	M2231	E	F	40±	Radius	42.1	15.2	3.2	−8.8	8.7
83	SJJ19	M2238	U	nan	6±	Fibula	17.1	6	3.4	−7.7	8
84	SJJ28	M2243	M	nan	13–16	Fibula	39.6	14.4	3.2	−7.8	8.7
85	SJJ10	M2247	U	nan	8±	Ulna	37.3	13.4	3.3	−8.1	7.9
86	SJJ45	M2249	M	F	20±	Fibula	39.6	14.1	3.3	−8	8.9
87	SJJ33	M2250	M	M	35±	Tibia	23	8.1	3.3	−7.8	10.3
88	SJJ4	M2256	E	M	25–30	Femur	22.5	7.8	3.3	−9.4	10.7
89	SJJ2	M2260	E	F	50±	Ulna	35.5	12.7	3.3	−9	10.6
90	SJJ38	M2273	U	nan	13–16	Fibula	18.6	6.9	3.1	−7.3	6.9
91	SJJ34	M2293	U	M	40–45	Fibula	18.7	6.4	3.4	−9	10.4

Period abbreviations: Early = Phase I (early Western Zhou), Middle = Phases II–III (middle Western Zhou), and Late = Phases IV–V (late Western Zhou), following [Su \(2025\)](#).

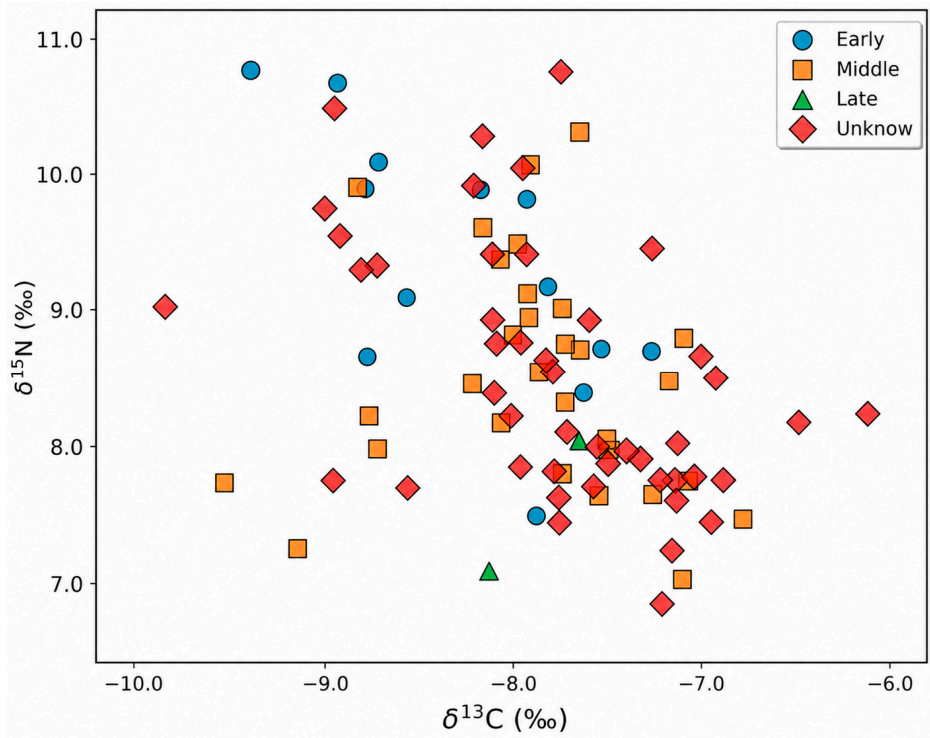


Figure 2. Scatter plot of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for the Jucun population.

4. Results

4.1. Collagen Quality Assessment

It is generally accepted that bone collagen is considered uncontaminated when the collagen yield exceeds 1%, the carbon content falls within 15.3–47%, the nitrogen content within 5.5–17.3%, and the atomic C/N ratio ranges between 2.9 and 3.6 ([Ambrose, 1990](#); [Bocherens et al., 1991](#); [Deniro, 1985](#); [Richards & Hedges, 1999](#)). All 91 samples yielded collagen contents greater than 1%. The carbon and nitrogen contents ranged from 16.4 to 43.8% and 5.7 to 15.6%, respectively, with C/N ratios between 2.9 and 3.5. These values fall within the accepted quality criteria, indicating that the collagen was well preserved and suitable for stable isotope analysis.

4.2. Overall Isotopic Results

Full stable carbon and nitrogen isotope data for the Jucun individuals are presented in detail in Table 1. For the entire study population ($n = 91$), $\delta^{13}\text{C}$ values vary between -9.8‰ and -6.3‰ , with a mean of $-8.0 \pm 0.7\text{‰}$; the mean $\delta^{15}\text{N}$ value is $8.6 \pm 0.9\text{‰}$. Correlation analysis revealed a significant negative relationship between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values (Pearson's $r = -0.436$, $p < 0.001$, $R^2 = 0.190$).

5. Discussions

5.1. Overall Dietary Structure and Subsistence Patterns of the Jucun Population

The Jucun population exhibits a typical C_4 -based dietary pattern, with a mean $\delta^{13}\text{C}$ value of $-8.0 \pm 0.7\text{‰}$ and a mean $\delta^{15}\text{N}$ value of $8.6 \pm 0.9\text{‰}$. The negative correlation between $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values suggests a certain degree of dietary variation within the Jucun population. Specifically, individuals with relatively more negative $\delta^{13}\text{C}$ values tend to exhibit slightly elevated $\delta^{15}\text{N}$ values, which may indicate that dietary variation was not primarily driven by differences in staple crop consumption, but rather by varying contributions of animal-derived foods and/or C_3 resources. Previous studies have shown that dietary differences within Western Zhou populations, particularly in access to animal-derived foods, were often associated with social identity and status. Therefore, the observed isotopic variation at Jucun may also reflect differences in food resource allocation among individuals (Sun, 2019; Hou et al., 2022; Li et al., 2020). However, a detailed investigation of the mechanisms underlying such variation is beyond the scope of the present study. As the archaeological investigation of the Jucun cemetery is still ongoing and additional information regarding individual identity and social status is becoming available, this issue will be explored in future research.

Combined with archaeobotanical and previous isotopic studies (Z. Zhao, 2014; Hou et al., 2022; Li et al., 2020; Sun, 2023; Z. Zhao & He, 2006), the $\delta^{13}\text{C}$ values indicate that the C_4 signal primarily derives from millet crops, which represent the most common staple in the region. This suggests that millet agriculture constituted the dominant component of the dietary system.

Establishing a faunal isotopic baseline is essential for interpreting human dietary patterns. However, due to the scarcity of animal remains at the Jucun cemetery, no faunal samples were available for isotopic analysis. Therefore, previously published data from southern Shanxi were used as a reference. Sun (2023) reported a mean $\delta^{15}\text{N}$ value of approximately 7.0‰ for animal remains from the region since the Middle Neolithic. Based on a commonly accepted trophic level enrichment of 3‰ , a threshold of 10.0‰ was defined to identify individuals with relatively high levels of animal protein consumption. According to this criterion, nine out of the 91 individuals exceed this threshold, including six males and three females (or probable females), indicating that only a small proportion of the population consumed elevated amounts of animal protein.

Zooarchaeological, isotopic, and ancient DNA studies indicate that domesticated animals played an increasingly important role in subsistence systems in the Yellow River region since the mid-Holocene (D. Cai & Sun, 2012; D. Cai et al., 2021; Guan et al., 2007; Lu et al., 2014; Yuan, 1999; Yuan, 2010). Among them, domestic animals in southern Shanxi during the Western Zhou period were mainly represented by pigs, dogs, and sheep, and were closely associated with a millet-based agricultural economy (Deng & Xie, 2026; Ban, 2023). However, isotopic evidence from northern China consistently shows that actual animal protein consumption remained relatively limited, despite the close association between humans and domesticates. These modest contributions of animal protein were primarily derived from livestock raised on millet by-products (Chen et al., 2012; Hou et al., 2022; Li et al., 2020). Although the study area was situated near riverine environments

and the exploitation of freshwater aquatic resources cannot be completely excluded, no substantial freshwater fish remains have been recovered from the Jucun cemetery or contemporaneous archaeological sites in southern Shanxi to date. Moreover, the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of the Jucun population closely resemble the isotopic characteristics of millet-farming communities in the region and do not exhibit patterns indicative of a significant contribution from freshwater aquatic resources. Therefore, the influence of the freshwater reservoir effect on the isotopic results presented here is considered to be minimal. In combination with the $\delta^{13}\text{C}$ values, this suggests that the limited animal protein intake observed in the Jucun population was likewise mainly sourced from domesticated animals sustained within a millet-based agricultural system.

These results indicate that the Jucun Di population maintained a stable dietary system dominated by C_4 millet crops, supplemented by limited amounts of animal protein, reflecting a subsistence strategy highly dependent on millet agriculture. This pattern contrasts with traditional interpretations derived from early Chinese texts, which often characterize Di groups as primarily pastoral or reliant on mobile herding economies. In contrast, the tightly clustered and stable $\delta^{13}\text{C}$ values observed at Jucun suggest a high degree of dietary homogeneity among individuals, indicating that millet agriculture formed the core of subsistence practices, while animal husbandry played only a supplementary role.

5.2. Dietary Changes of the Jucun Population During the Western Zhou

Building on the overall dietary characteristics of the Jucun population, this section examines diachronic changes in subsistence practices following the migration of Di groups into southern Shanxi. Based on established archaeological phase divisions, the analyzed individuals were grouped into Early, Middle, and Late Western Zhou periods to explore temporal variation in staple consumption and animal protein intake. The statistical results are presented in Table 2, and the distributions of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values for each phase are illustrated in Figure 3.

Table 2. Comparison of isotope values of people in different periods in Jucun cemetery.

Group Type	Group	<i>n</i>	$\delta^{13}\text{C}$ (‰)	<i>p</i> Value	$\delta^{15}\text{N}$ (‰)	<i>p</i> Value	Methods
Period	Early	13	-8.3 ± 0.6	0.24	9.3 ± 0.9	0.01 *	Kruskal–Wallis test
	Middle	30	-8.0 ± 0.6		8.5 ± 0.8		
	Late	2	-8.0 ± 0.3		7.6 ± 0.7		

0.01 *, <0.05 , significant difference, $\alpha = 0.05$. According to the study of Su (2025), the Early period corresponds to Phase I, the Middle period corresponds to Phases II–III, and the Late period corresponds to Phases IV–V.

Due to the small sample size of the late period ($n = 2$), the non-parametric Kruskal–Wallis test, which does not require normally distributed data, was used for the temporal comparison. The results show no significant difference in $\delta^{13}\text{C}$ values among the Early, Middle, and Late periods ($p = 0.24$). The $\delta^{13}\text{C}$ values remained consistently distributed within the range dominated by C_4 plants, with only a slight upward trend in the median, indicating that C_4 millet crops were the absolute staple throughout the occupation, reflecting a stable reliance on millet agriculture.

In contrast, a significant difference was observed in $\delta^{15}\text{N}$ values across the three periods ($p = 0.01 < 0.05$). As shown in the boxplot (Figure 3b), both the median and the distribution range of $\delta^{15}\text{N}$ values declined continuously from the Early to the Late Western Zhou period, indicating a significant reduction in animal protein intake over time. Combined with the stable $\delta^{13}\text{C}$ values, this suggests that the dietary strategy of the Jucun Di people became increasingly focused on C_4 millet agriculture after their migration to southern Shanxi. While millet remained the dominant staple, the contribution of animal husbandry

and animal protein likely decreased, possibly reflecting an increasing adaptation to and reliance on the local millet agricultural system.

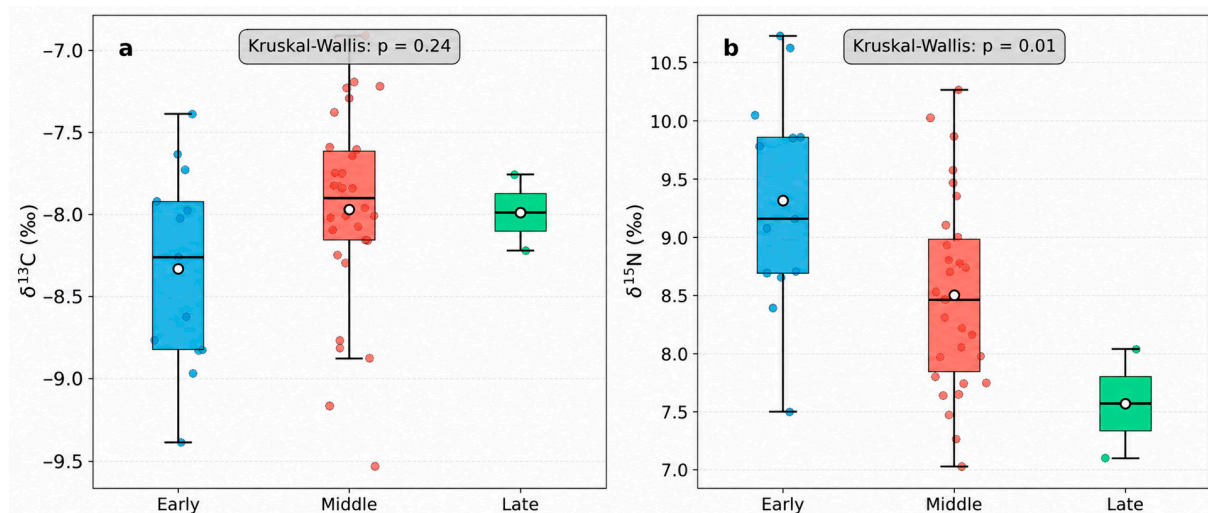


Figure 3. Comparison of Isotopic Distributions Among Periods at Jucun Cemetery: (a) Boxplot of $\delta^{13}\text{C}$ distribution differences; (b) Boxplot of $\delta^{15}\text{N}$ distribution differences.

In addition, judging from the degree of dispersion shown in the boxplots, the $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values of the early-phase samples display wider ranges, whereas the data from the middle and late phases become progressively more concentrated around the center, with a marked reduction in variability. This shift from “dispersion” to “concentration” suggests that dietary practices differed more substantially among individuals during the initial stage after migration. As adaptation to the local millet-based agricultural system deepened, the subsistence strategies of the population gradually converged, ultimately resulting in a unified and stable dietary pattern characterized by millet as the staple and low animal protein intake.

It should be noted that the late-phase sample consists of only two individuals. Therefore, the declining trend in $\delta^{15}\text{N}$ values should be interpreted with caution. This result is more indicative of the overall direction of change from the early and middle phases to the late phase, rather than the absolute dietary level of the late-phase population.

5.3. Dietary Formation of Migrant Di Populations in the Core Region of the Central Plains

To further understand the formation of the dietary structure of the Di population at the Jucun cemetery, it is necessary to examine this group within a broader framework of population origins and regional subsistence background.

Archaeological studies indicate that the cultural composition of the Di populations at both Jucun and Hengshui cemeteries includes elements that can be traced back to the Lijiaya culture (Su, 2025; Y. Yang, 2023). The Lijiaya culture, which developed after the Shimao culture, was a major archaeological culture that emerged during the late Shang period (ca. 1400–1100 BCE) and was primarily distributed in what is now northern Shaanxi and northwestern Shanxi (T. Zhang, 2016). Its core area lay along the Loess Plateau region where the Yellow River flows southward, a transitional zone between the northern steppe and the agricultural societies of the Central Plains, commonly regarded as a typical agro-pastoral ecotone (Huang et al., 2021).

Recent lipid residue analyses of pottery from Lijiaya culture sites (e.g., the Xinzhuang site) have shown that food processing and consumption in this region were characterized by considerable diversity, reflecting a subsistence system that combined agriculture and animal husbandry (Yan et al., 2026). This evidence suggests that Lijiaya populations

adopted relatively flexible subsistence strategies, and that their dietary structure was not solely dependent on millet agriculture.

However, in contrast to this potential population background, isotopic analysis of the Jucun cemetery indicates that this group had already developed a stable dietary structure dominated by C₄ millet crops, with relatively limited intake of animal protein. The $\delta^{13}\text{C}$ values are tightly clustered within the typical C₄ dietary range, with low inter-individual variation, reflecting a highly consistent pattern of food consumption. Such a dietary structure, centered on a single agricultural resource, differs markedly from the more diversified patterns of food exploitation typically observed in populations inhabiting agro-pastoral ecotones.

At the same time, no archaeological remains that can be clearly attributed to the transition from the late Shang to the early Western Zhou period—nor any that can be directly linked to the Lijiaya culture—have been identified at or near the Jucun cemetery. This apparent archaeological “gap” further supports the interpretation that this population represents an intrusive, migrant group. According to previous studies, in the early phase of its establishment, the Western Zhou state implemented a series of population movements and spatial reorganizations to consolidate its control over southern Shanxi and surrounding regions. Among these, the relocation to Jin state of Xiefu (燹父), a vassal lord enfeoffed in southern Shanxi during the early Western Zhou Dynasty, is widely regarded as a pivotal event shaping the political structure of this region. During this process, Rong and Di groups that had previously been active in the Loess Plateau of northern Shaanxi and northwestern Shanxi may have been deliberately relocated into the southern Shanxi plain by the Zhou rulers, possibly in recognition of their role during the transition from the Shang to the Zhou (Y. Yang, 2023). In this new setting, they likely assumed functions related to regional defense and governance, serving as a protective buffer for the Zhou state.

Against this background, the formation of the dietary structure of the Di population at Jucun should not be simply understood as a passive adaptation to a new environment, but rather as a process shaped by the combined influences of migration, political integration, and the regional economic system. After entering southern Shanxi—where a long-established agricultural economy centered on millet cultivation had been firmly in place—these populations, originally from an agro-pastoral ecotone and reliant on diverse subsistence strategies, gradually adjusted their modes of food acquisition toward the local agricultural structure. This shift is ultimately reflected in the isotopic evidence as a stable dietary pattern dominated by C₄ millet resources.

By further integrating the isotopic results with the archaeological evidence from the Jucun cemetery, a more consistent pattern of change can be observed. Su (2025), in an analysis of the chronological phases and cultural elements of the site, noted that during the early Western Zhou period the population still retained certain aspects of its own cultural traditions. While individuals of higher and middle status largely conformed to Zhou cultural norms in the use of ritual bronzes, ordinary individuals continued to display some differences in ceramic assemblages and burial practices (Su, 2025). By the late Western Zhou period, however, these differences gradually diminished, and the influence of Zhou cultural elements became increasingly pronounced, with the inheritance of earlier cultural traditions progressively weakening. This conclusion, from the perspective of material culture, indicates a continuous strengthening of Zhou cultural identification among the Jucun population during the Western Zhou period.

These changes at the level of material culture are highly consistent with the dietary trends reflected in the isotopic data. As demonstrated in the preceding diachronic analysis, $\delta^{13}\text{C}$ values for the Jucun population remain stable within the range dominated by C₄ crops from the early to the late Western Zhou period, whereas $\delta^{15}\text{N}$ values show a continuous

decline, indicating an increasing reliance on millet agriculture and a gradual reduction in animal protein intake. The convergence of dietary structure from a relatively diverse pattern toward a more uniform, agriculture-dominated system corresponds temporally with the archaeological evidence for diminishing cultural differences and the progressive strengthening of Zhou cultural identification.

This pattern of convergence, occurring simultaneously in both dietary structure and material culture, indicates that after migrating into the southern Shanxi plain, the Di population at Jucun did not merely adapt to the local environment at an economic level. Rather, through continuous generational turnover, they gradually became integrated into a regional social system centered on Zhou cultural traditions. As one of the most fundamental and stable aspects of daily life, diet provides a sensitive indicator of such processes. Changes in dietary structure reflect adjustments in resource use and subsistence strategies, and at the same time constitute a direct expression of cultural integration at the bioarchaeological level.

At a regional scale, when populations of different origins and cultural affiliations—such as those from Jucun, Hengshui, and Xi'nancheng—are considered within a unified comparative framework, their $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values show a high degree of overlap in overall distribution (Figure 4), all consistently falling within the isotopic range dominated by C_4 millet-based agriculture in southern Shanxi (Table 3). Although minor differences can be observed, with the Jucun population exhibiting a slightly stronger C_4 signal and relatively lower animal protein intake, these variations do not alter the overall similarity in dietary structure among the three groups.

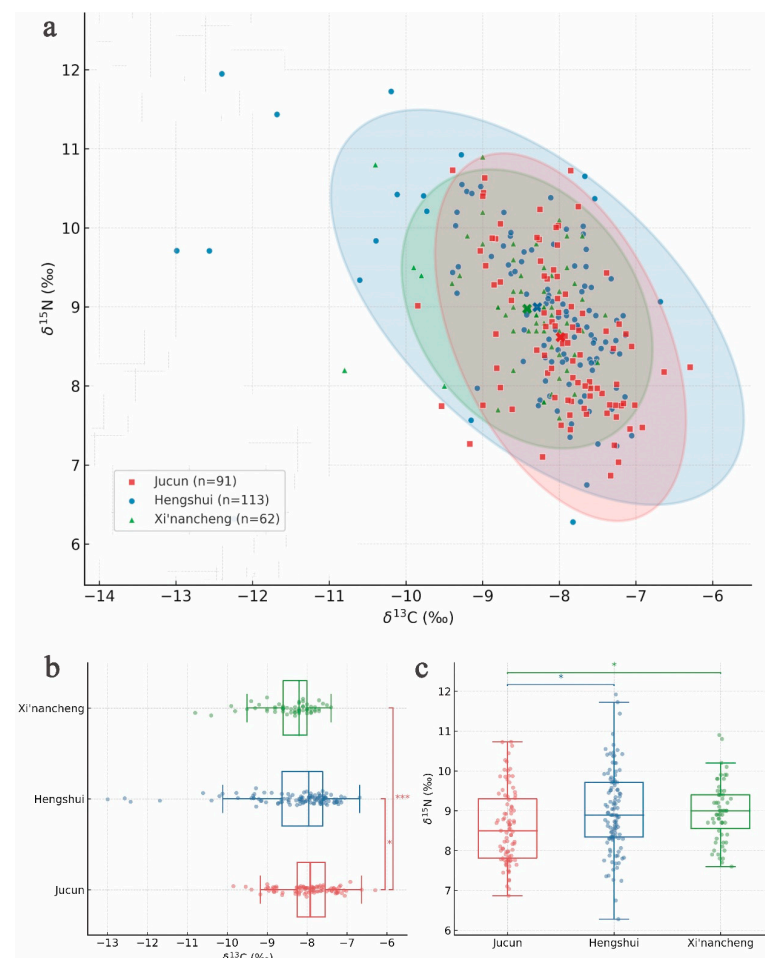


Figure 4. Comparative carbon and nitrogen isotope results for human individuals from the Western Zhou cemeteries of Jucun (睢村), Hengshui (横水), and Xi'nancheng (西南呈), the latter of which is

located in southeastern Shanxi and belongs to the broader cultural–geographical region of southern Shanxi. (a) Bivariate plot of $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ values with 1 SD ellipses showing site-specific distributions; (b) boxplot comparison of $\delta^{13}\text{C}$ values; (c) boxplot comparison of $\delta^{15}\text{N}$ values. Asterisks indicate levels of statistical significance: * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$. Comparisons between Hengshui and Xi’nancheng were not significant ($\delta^{13}\text{C}$: $p = 0.330$; $\delta^{15}\text{N}$: $p = 0.903$).

Table 3. Summary Statistics of Human Isotopic Values, Southern Shanxi (Neolithic to Western Zhou Period).

Site ^a	Age/Dynasty	<i>n</i>	$\delta^{13}\text{C}$ (‰)	$\delta^{15}\text{N}$ (‰)	Ref.
Qingliangsi-1	Neolithic	87	-8.2 ± 1.8	9.3 ± 1.3	(Shu, 2016)
Qingliangsi-2	Neolithic	27	-8.1 ± 0.9	8.5 ± 1.1	(Lin et al., 2010)
Taosi-1	Neolithic	3	-11.3 ± 1.6	nan	(L. Cai & Qiu, 1984)
Neiyangyuan	Xia	2	-7.4 ± 0.1	8.5 ± 0.1	(Pei et al., 2008)
Taosi-2	Xia	12\7 ^b	-6.3 ± 1.1	8.9 ± 1.3	(X. Zhang et al., 2007)
Qiaobei	Late Shang—Early Zhou	3	-7.7 ± 0.1	8.1 ± 0.7	(Y. Wang, 2013)
Hengshui	Western Zhou	113	-8.3 ± 1.1	9.0 ± 1.0	(Sun, 2019)
Xi’nancheng	Western Zhou	62	-8.4 ± 0.7	9.0 ± 0.7	(Li et al., 2020)
Jucun	Western Zhou	91	-8.0 ± 0.6	8.6 ± 0.9	this paper

Notes: ^a Site-1, Site-2 denote data from two research groups; ^b $\delta^{15}\text{N}$ data are only available for 7 samples.

One noteworthy pattern is that the Xi’nancheng population displays slightly lower $\delta^{13}\text{C}$ values than those from Jucun and Hengshui. Xi’nancheng is located in the Changzhi Basin of southeastern Shanxi and differs to some extent from the southern Shanxi region in local environmental conditions. Previous studies conducted on the Chinese Loess Plateau have shown that the carbon isotope composition of millet crops is sensitive to precipitation and water availability during the growing season, with precipitation being one of the primary controlling factors of millet $\delta^{13}\text{C}$ values (Q. Yang & Li, 2015; Q. Yang et al., 2016). Therefore, the relatively more negative $\delta^{13}\text{C}$ values observed at Xi’nancheng may partly reflect regional environmental variation between the two areas. However, because detailed paleoenvironmental data directly comparing the Changzhi Basin and southern Shanxi during the Western Zhou period are currently unavailable, this interpretation should be regarded as tentative. In addition, the Xi’nancheng cemetery primarily dates to the middle and late Western Zhou period, and its isotopic differences may also reflect localized dietary changes during the later phases of the Western Zhou. Nevertheless, these subtle differences do not undermine the broad dietary similarities observed among the three populations.

In summary, the dietary structure of the Di population represented by the Jucun cemetery does not reflect a continuation of their original subsistence traditions. Rather, it represents a newly established and stable pattern formed through the rapid integration into the millet-based agricultural system of southern Shanxi within a context of migration. This process reflects the mechanisms of subsistence restructuring and cultural integration experienced by migrant populations in the core regions of the Central Plains, and provides important bioarchaeological evidence for understanding population interaction and the development of Huaxia identity during the Western Zhou period.

6. Conclusions

This study, based on stable carbon and nitrogen isotope analysis of human skeletal remains excavated from the Jucun cemetery, investigates the dietary structure and its formation mechanisms of the Di population that migrated into southern Shanxi during the Western Zhou period. The main conclusions are as follows:

- (1) The Jucun population exhibits a subsistence pattern overwhelmingly dominated by C4 millet-based crops, with generally low levels of animal protein intake. Their economic system was already centered on sedentary millet agriculture, rather than the traditionally assumed pastoral mode of subsistence.
- (2) After migrating into southern Shanxi, the Jucun population completed the transition to the local millet-based agricultural system within a relatively short period. Over time, they became one of the groups most strongly reliant on millet-based plant foods in the region.
- (3) The increasing dietary homogenization of the Di population at Jucun corresponds temporally with their growing identification with Zhou culture, reflecting a synchronous integration into Central Plains society at both economic and cultural levels.

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References

- Ambrose, S. H. (1990). Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archaeological Science*, 17, 431–451. [\[CrossRef\]](#)
- Ambrose, S. H. (1993). Isotopic analysis of paleodiet: Methodological and interpretive considerations. In M. K. Sandford (Ed.), *Investigations of ancient human tissue: Chemical analysis in anthropology* (pp. 59–130). Gordon and Breach Science Publishers.
- Ban, L. (2023). *Research on animal remains unearthed from the Hengshui graveyard of Western Zhou dynasty at Jiang county in Shanxi province* [Master's thesis, Jilin University].
- Bocherens, H., & Drucker, D. (2003). Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: Case studies from recent and ancient terrestrial ecosystems. *International Journal of Osteoarchaeology*, 13, 46–53. [\[CrossRef\]](#)
- Bocherens, H., Fizet, M., Mariotti, A., Lange-Badre, B., Vandermeersch, B., Borel, J. P., & Bellon, G. (1991). Isotopic biogeochemistry (^{13}C , ^{15}N) of fossil vertebrate collagen: Application to the study of a past food web including Neandertal man. *Journal of Human Evolution*, 20, 481–492. [\[CrossRef\]](#)
- Cai, D., & Sun, Y. (2012). On the origin of the ancient DNA of domestic animals in China. *Research of China's Frontier Archaeology* 边疆考古研究, 11, 445–455.
- Cai, D., Zhang, N., & Zhao, X. (2021). Study on the origin and spread of Chinese goat. *Cultural Relics in Southern China* 南方文物, 1, 191–200.
- Cai, L., & Qiu, S. (1984). Determination of Carbon-13 and study of ancient recipes. *Archaeology* 考古, 10, 949–955.
- Cao, Y. (2022). *A study on Rong Di in Shanxi during the Late Shang and Western Zhou dynasties* [Master's thesis, Shanxi Normal University].
- Chen, X., Yuan, J., Hu, Y., He, N., & Wang, C. (2012). A preliminary exploration to the domestic animal raising strategy: The evidences from carbon and nitrogen isotope analyses. *Archaeology* 考古, 9, 75–82.
- Chisholm, B. S., Nelson, D. E., & Schwarcz, H. P. (1982). Stable-carbon isotope ratios as a measure of marine versus terrestrial protein in ancient diets. *Science*, 216, 1131–1132. [\[CrossRef\]](#) [\[PubMed\]](#)
- Christine, A. H. (2017). *The social archaeology of food: Thinking about eating from prehistory to the present* (p. 3). Cambridge University Press.
- Deng, H., & Xie, Y. (2026). Zooarchaeological analysis of animal offerings from the Western Zhou Dahekou cemetery, Yicheng, Shanxi. *Cultural Relics in Southern China*, 2026(2), 157–166.
- Deniro, M. J. (1985). Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to palaeodietary reconstruction. *Nature*, 317, 806–809. [\[CrossRef\]](#)
- Deniro, M. J., & Epstein, S. (1981). Influence of diet on the distribution of nitrogen isotopes in animals. *Geochim Cosmochim Acta*, 45, 341–351. [\[CrossRef\]](#)
- Guan, L., Hu, Y., Tang, Z., Yang, Y., Dong, Y., Cui, Y., & Wang, C. (2007). C, N stable isotope analysis of Tonghua Wanfabozi pig. *Chinese Science Bulletin* 科学通报, 52(14), 1678–1680. [\[CrossRef\]](#)

- Han, T., & Gao, S. (2025). A study of the Western Zhou population from the Jucun cemetery in Jiangxian county, Shanxi province. *Wenwu Chunqiu*, 6, 10–20.
- Hobson, K. A., & Welch, H. E. (1992). Determination of trophic relationships within a high arctic marine food web using $\delta^{13}\text{C}$ and $\delta^{15}\text{N}$ analysis. *Marine Ecology. Progress Series (Halstenbek)*, 84, 9–18. [\[CrossRef\]](#)
- Hou, L., Sun, Y., Sun, X., Yang, S., Wang, H., Xie, Y., Zhu, H., & Zhang, Q. (2022). Social hierarchy of the Peng state in the Western Zhou dynasty: Stable isotope analysis of animals and humans from the Hengshui cemetery, Shanxi, China. *Journal of Archaeological Science: Reports*, 44, 103522. [\[CrossRef\]](#)
- Hsu, C. (1965). *Western Chou civilization*. Yale University Press.
- Huang, X., Zhang, J., Ren, L., Zhang, S., & Chen, F. (2021). Intensification and driving forces of pastoralism in northern China 5.7 Ka ago. *Geophysical Research Letters*, 48, e2020GL092288. [\[CrossRef\]](#)
- Katzenberg, M. A. (2007). Stable isotope analysis: A tool for studying past diet, demography, and life history. In *Biological anthropology of the human skeleton: Second edition* (pp. 411–441). Wiley-Liss.
- Kern, M. (2009). Bronze inscriptions, the Shijing and the Shangshu: The evolution of the ancestral sacrifice during the Western Zhou. In *Handbook of oriental studies. Section 4, China* (Vol. 21-1, pp. 143–200). Brill Academic Publishers.
- Lee-Thorp, J. A. (2008). On isotopes and old bones. *Archaeometry*, 50, 925–950. [\[CrossRef\]](#)
- Li, X., Zhang, S., Lu, M., Qiu, M., Wen, S., & Ma, M. (2020). Dietary shift and social hierarchy from the Proto-Shang to Zhou dynasty in the central plains of China. *Environmental Research Letters*, 15, 35002. [\[CrossRef\]](#)
- Lin, X., Chen, L., Xue, X., & Zhao, C. (2010). Stable isotopic analysis of human bones from the Qianliang temple graveyard, Ruicheng county, Shanxi province. *Quaternary Sciences*, 30, 415–421.
- Lu, P., Yuan, J., & Li, Z. (2014). Further discussion on the origin of domestic cattle in China—Discussion on the paper “Morphological and genetic evidence of early Holocene cattle management in northeast China”. *Cultural Relics in Southern China* 南方文物, 3, 48–59.
- Pei, D., Hu, Y., Yang, Y., Zhang, Q., Zhang, G., Tian, J., & Wang, C. (2008). Paleodietary analysis of humans from the Neiyangyuan site of Xiangning, Shanxi province. *Acta Anthropologica Sinica*, 27(4), 379–384. [\[CrossRef\]](#)
- Qu, J. (2021). Double-track governance in traditional Chinese society: Dialectics between the enfeoffment system of fiefdom and the bureaucratic prefectural system. *Chinese Journal of Sociology*, 7, 347–389. [\[CrossRef\]](#)
- Richards, M. P., & Hedges, R. E. M. (1999). Stable isotope evidence for similarities in the types of marine foods used by late Mesolithic humans at sites along the Atlantic coast of Europe. *Journal of Archaeological Science*, 26, 717–722. [\[CrossRef\]](#)
- Schoeninger, M. J., & Deniro, M. J. (1984). Nitrogen and carbon isotopic composition of bone collagen from marine and terrestrial animals. *Geochim Cosmochim Acta*, 48, 625–639. [\[CrossRef\]](#)
- Shu. (2016). Dietary Analysis I. In Shanxi Provincial Institute of Archaeology, Yuncheng Municipal Workstation of Cultural Heritage & Ruicheng County Administration of Tourism and Cultural Heritage (Eds.), *The prehistoric cemetery of Qingliangsi* (pp. 519–537). Cultural Relics Press.
- Su, Y. (2025). *A research of the JUCUN cemetery in Jiangxian, Shanxi* [Master’s thesis, Shanxi University].
- Sun, Y. (2019). *Carbon and nitrogen stable isotope of the human and animal bones from the Hengshui cemetery* [Master’s thesis, Shanxi University].
- Sun, Y. (2023). *Stable carbon and nitrogen isotope study of human bones from Dahekou Western Zhou cemetery in Yicheng, Shanxi* [Ph.D. thesis, Jilin University].
- Vander Zanden, M. J., Cabana, G., & Rasmussen, J. B. (1997). Comparing trophic position of freshwater fish calculated using stable nitrogen isotope ratios ($\delta^{15}\text{N}$) and literature dietary data. *Canadian Journal of Fisheries and Aquatic Sciences*, 54, 1142–1158. [\[CrossRef\]](#)
- Wang, J. (2016). Jucun Western Zhou cemetery at Jiang village. In *Yearbook of archaeology in China 2015*. China Social Science Press.
- Wang, Y. (2013). *A Preliminary study on the relationship between social class and diet structure: A case study of Niedian and Fushan Qiaobei sites* [Master’s thesis, University of Chinese Academy of Sciences].
- Xie, Y. (2019). *Six hundred years of the rise and fall of the Jin state*. Sanjin Publishing House.
- Yan, L., Chen, K., Ma, Q., Sun, Z., Chu, H., & Ma, Y. (2026). A study on the subsistence strategy of the Qingjian Xin Zhuang site in northern Shaanxi region during the late Shang period: A perspective from lipid residues in pottery. *Archaeological and Anthropological Sciences*, 18, 43. [\[CrossRef\]](#)
- Yang, Q., & Li, X. (2015). Investigation of the controlled factors influencing carbon isotope composition of foxtail and common millet on the Chinese loess plateau. *Science China Earth Sciences*, 58, 2296–2308. [\[CrossRef\]](#)
- Yang, Q., Li, X., Zhou, X., Zhao, K., & Sun, N. (2016). Quantitative reconstruction of summer precipitation using a mid-Holocene $\delta^{13}\text{C}$ common millet record from Guanzhong Basin, northern China. *Climate of the Past*, 12, 2229–2240. [\[CrossRef\]](#)
- Yang, Y. (2023). *Archaeological research on the cathayization of the Rongdi ethnic group in the Western Zhou dynasty in the southern Shanxi province*. Jilin University.
- Yuan, J. (1999). Man’s meat-acquiring patterns in neolithic China. *Acta Archaeologica Sinica* 考古學報, 1, 1–22.

- Yuan, J. (2010). Zooarchaeological study on the domestic animals in ancient China. *Quaternary Sciences* 第四紀研究, 30, 298–306.
- Zhang, T. (2016). Shang dynasty archaeological cultures on northern Shaanxi plateau. *Journal of National Museum of China*, 9, 18–30.
- Zhang, X., Qiu, S., Bo, G., Wang, J., & Zhong, J. (2007). Analysis of carbon and nitrogen in some human bones from Erlitou and Taosi sites. In Center For Scientific Archaeology IOAC (Ed.), *Science of archaeology II* (pp. 41–48). Science Press.
- Zhao, H. (2018). *A research on the human skeletons from Jucun graveyard in Jiang county of Shanxi province*. Jilin University.
- Zhao, Z. (2014). The process of origin of agriculture in China: Archaeological evidence from flotation results. *Quaternary Sciences* (Disiji Yanjiu 第四紀研究), 1, 73–84.
- Zhao, Z., & He, N. (2006). Flotation results from the remains excavated on the Taosi city-site in 2002 and their analysis. *Archaeology* (Kaogu 考古), 5, 77–86. [[CrossRef](#)]
- Zhu, H. (2004). *Physical anthropology*. Higher Education Press.

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