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Pig Management Strategies in the East Liao River Basin From the Bronze Age (c. 2000–256 BC) to the Liaojin Dynasties (907–1234 AD): Stable Isotope Analysis of Animals at the Changshan Site, Jilin Province, China

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Pig domestication and management strategy has been increasingly discussed in recent years, focusing on the temporal-spatial differences of pig management strategies. The East Liao River Basin with diverse ecosystems, cultural exchanges, and collisions plays an important role in the cultural development, exchange, and integration processes between Northeast China and the Central Plains. Multiple studies have revealed that various forms of subsistence economy, such as nomadism, fishing and hunting, and farming, existed in this region. However, no report or discussion has been presented concerning the status of domestic animal management strategies over a long-term in the East Liao River Basin. Carbon and nitrogen stable isotopes analysis were performed on the fauna bones at the Changshan site in Siping, Jilin, China, from the Bronze Age (c. 2000–256 BC) to the Liaojin Dynasties (907–1234 AD), to reconstruct their dietary pattern and reveal the status of domestic animal management strategies, especially the diachronic changes in pig feeding strategies. The results showed that pigs (–19.3 ± 1.6%, 5.3 ± 0.9%, $n = 27$), horses (–18.4 ± 1.7%, 4.8 ± 1.4%, $n = 7$), and sheep (–19.8 ± 1.5%, 5.7 ± 0.5%, $n = 6$) primarily received their subsistence through C_3-based food. Nevertheless, cattle (–16.4 ± 3.5%, 6.0 ± 2.1%, $n = 2$) and the past human (–13.9%, 10.3%, $n = 1$) lived on mixed C_3/C_4-based food. Notably, the stable isotope data for pigs from the Bronze Age (–19.1 ± 2.0%, 5.4 ± 1.0%, $n = 9$) to the Liaojin Dynasties (–19.8 ± 0.6%, 5.1 ± 0.7%, $n = 15$) were similar, indicating that the management and/or feeding strategy of domestic pigs were relatively stable with a free range in a wild ecosystem over a long period. Related studies have shown that pigs in captivity were mainly fed by millet-based food in the West Liao River Basin and the middle reaches of the Yellow River valley, where millet agriculture were adequately developed. Abundant natural resources, including plants, wild animals, and fishes, could provide sufficient food to the past population in the East Liao River Basin. Thus, the millet-based agriculture was just an auxiliary subsistence strategy in the Changshan site, leading to a gap in the driving force for long-term intensive management of pig.

Keywords: The East Liao River Basin, Changshan site, carbon and nitrogen stable isotopes, pig management strategy, free-range

INTRODUCTION

The domestication of pigs resulted in the widespread adoption of pigs as meat resources worldwide, especially in China. Today there are more than one billion pigs worldwide. 'Each place has its own way of supporting its own inhabitants', and the past human and animals in different temporal-spatial environments relied on various natural resources, which resulted in huge differences in subsistence patterns. This was similar to pig management strategy.

Multiple studies have revealed that the utilization of millets by domestic dogs was detected at the Nanzhuangtou site, around 10,000 years ago (Yuan and Li 2010; Hou et al., 2021). However, no evidence was found regarding domestic pigs during this period in China. Pigs with direct signs of domestication were found in Jiahu site around 9,000 years ago (Luo 2012). Thereafter, pig became an important animal in the Neolithic period (Song, 2012). Based on the millet-based agriculture, the past populations fed pigs at many current archaeological sites, such as the Dadiwan (Qi et al., 2006), Peiligang (The Institute of Archaeology, Chinese Academy of Social Sciences 1996), Cishan (Zhou 1981; Yuan, 2001), and Xinglonggou (Dong et al., 2007; Zhang et al., 2017) sites, around c. 6,000 BC–5,000 BC, in the middle portions of the Yellow River valley and the West Liao River Basin. The domestic pigs were placed at the bottom of the pits at the Cishan site, indicating that millet growth had developed to the extent that it could sustain pigs feeding at that time (Tong 1984). Under the millet-based agricultural background, pig feeding strategies were obvious in northern China from the Neolithic Periods to the Bronze Age (e.g., Guan et al., 2011; Hou 2019). In other words, captive pigs were fed with millet-based food, including millet and/or millet by-products, table scraps, and human faeces.

Different pig management strategies were also observed in the Huai River valley (e.g., Dai and Zhang 2021), the Yangtze River Basin (e.g., Guan et al., 2008; Guo et al., 2011; Zhang et al., 2015; Guan et al., 2019; Dong and Yuan 2020; Yuan et al., 2020; Hongo et al., 2021; Hu 2021), and the Pearl River (e.g., Wang, 2018Wang, 2018; Liu et al., 2021), as well as the beach area (Wang et al., 2011). Multiple lines of evidence have revealed that the past populations in southern China preferred wild resources supplemented by the limited exploitation of domestic pigs (Dong and Yuan 2020; Yuan et al., 2020; Hongo et al., 2021). Consequently, the driving force for intensive management of domestic pigs was inadequate, with most pigs being free-range and fed in the wild ecosystem (Dong and Yuan 2020). With the development of rice-based agriculture in the above regions, the pigs started receiving rice-based food, including rice by-products, table scraps, and even human faeces (e.g., Guan et al., 2011; Hou 2019). However, wild plants and rice belong to C_3 plants, with a low $\delta^{13}C$ average (–26.5‰) (Ambrose 1991). Thus, we could not detect the extent of rice-based food consumption in pig diets. Notably, heavy dependence on rice-based food protein leads to an increase in the $\delta^{15}N$ value of animal tissues (e.g., Guan et al., 2007; Hu et al., 2009). Thus, the $\delta^{15}N$ values could help detect the feeding strategies in southern China.

The extent and status of the development of agriculture in the East Liao River Basin remains ambiguous, including the status of pig management strategies. The East Liao River Basin (**Figure 1**) contains rich relics of human activities dated as early as the Neolithic Age. For example, in the Houtao Muga site, which is a Neolithic archaeological site (c. 4500–3000 BC), faunal bones were dominated by large and medium-sized mammals (e.g., pigs, dogs, cattle, sheep, and deer), while large numbers of birds and fishes were also present (Wang et al., 2017; Liang et al., 2020; Song et al., 2017; Tang et al., 2017a). Wild faunal bones (e.g., Mongolian rabbits, ring-necked pheasants, wild boars, Przewalski's gazelle, and fish) and domestic dogs (Zhang et al., 2012) were found in the Shuangta site (c. 3500–3000 BC). Clearly, a broad-spectrum subsistence economy consisting of hunters and gatherers was predominantly observed in this region, and the previous populations primarily relied on abundant natural resources. In the Bronze Age (c. 2000–256 BC), numerous archaeological sites and animal remains were found in the East Liao River Basin. Domestic pigs were first found at the Dawangshan site (c. 2000–1000 BC) (Fan et al., 2014; Zhang et al., 2012; Tang et al., 2017b) and Wangqing River site (c. 2000–500 BC) (Song and Chen 2016) among various animal assemblages (e.g., red deer, roe deer, wild boar, birds, pigs, dogs, and sheep), indicating that pig feeding was only an auxiliary subsistence strategy. In the Liaojin Dynasties (907–1234 AD), at the Yinjia Wobao site, the proportions of animal bones of fish and mammals were 34.0 and 31.0%, respectively, indicating that fishing and hunting economy remained a dominant secondary strategy in this region (Shi et al., 2017; Liang et al., 2018). However, agricultural tools, such as iron sickles, saws, and axes were also found at the Aodongcheng site (Wang et al., 2006), which is located close to and is contemporary with the Yinjia Wobao site, indicating that the development of agriculture also followed an auxiliary subsistence strategy. It should be noted that the cultural sequence of the Wanfa Bozi site (**Figure 1**) is successive (Jilin Provincial Institute of Cultural Relics and Cultural Relics Management Office of Tonghua 2019), covering a period from the Neolithic period (c. 4000–2000 BC) to the Ming Dynasty (1368–1644 AD). Based on archaeological assemblage's research, it can be concluded that hunting-gathering-fishing was the primary subsistence strategy at this site (Yu and Jin 2018). Meanwhile, pigs were also fed by the past populations for the supplementary meat recourses from the Bronze Age (c. 1600–256 BC) (Tang et al., 2006). Guan et al. (2007) were the first to report pig isotopic results at the Wanfa

FIGURE 1 | Map of mainland China showing the location of the Changshan site in Jilin Province and the additional archaeological sites mentioned in the text (Original Image Source: http://bzdt.ch.mnr.gov.cn) (1. Changshan site, 2. Wanfa bozi site, 3. Xinglonggou site, 4. Xinzhai site, 5. Erlitou site, 6. Taosi site, 7. Zhangdeng site).

Bozi site in the East Liao River Basin during the historical period. Their results found the diet of pigs with more protein compared with those of wild boar. While this is regarded as pioneering research, it was limited in scope by just distinguishing between wild boar and domestic pigs (Guan et al., 2007).

Finally, the utilization of natural resources with a broad-spectrum economy was a dominant strategy in the East Liao River Basin over a long-term, starting from the Neolithic Age (c. 4500–3000 BC) and the Bronze Age (c. 2000–256 BC) to the Liaojin Dynasties (907–1234 AD), and a small amount agricultural economy was also detected.

After carefully considering these existing achievements in the East Liao River Basin, we found at least two problems. First, no report or discussion has been found concerning the status of pig management strategies systematically. What was the role of pigs in people's lives? Second, no research has constructed a systematic discussion over an extended period. Was there any change in pig management strategy over a long-term, especially with the continuous influence of agriculture development?

In this study, we conducted a stable isotope analysis of faunal remains from the Changshan site (Lin et al., 2018), from the Bronze Age (c. 2000–256 BC) to the Liaojin Dynasties (907–1234 AD), to reconstruct their diet and management strategies. The isotopic data was compared with previously published data from the central plains and Northeast China in the Bronze Age (c. 2000–256 BC) and historical periods (Guan et al., 2007; Chen et al., 2012; Hou et al., 2013; Dai et al., 2016; Zhang et al., 2017) to better understand pig management strategies in the East Liao River Basin.

ARCHAEOLOGICAL CONTEXTS

Archaeological Background

The Changshan site (43°44′ E, 124°25′ N) is located in the Changshan village, Lishu county, Siping city, Jilin Province, the average altitude is about 160 m and it is located 1,000 m from the East Liao River in the north (**Figure 1**).

In 1983, the Changshan site was discovered at the census of cultural relics (Jilin Province Cultural Relics Editing Committee 1984). Two systematic excavations were conducted in 2016 and 2017. The total excavated area was up to 3,225 square metres. A total of 378 ash pits, 18 ash ditches, 19 tombs, and 23 houses were discovered. Additionally, 33 pieces of pottery were restored, and nearly 2,300 pieces of stone-bone clams and metalware were studied (Lin et al., 2018). Abundant stoneware, pottery, and faunal remains were found, dating to the Neolithic Period (c. 4000–2500 BC), the Bronze Age (c. 2000–256 BC), and Liaojin Dynasties (907–1234 AD) (Lin et al., 2018). The excavated area in 2016 was about 975 square metres (**Figure 2**), and the faunal bones studied in this research were selected from this area.

Zooarchaeolical Analysis

Numerous faunal remains were unearthed at the Changshan site, around 30 specimens, including pigs [number of identifiable specimens (NISP = 297)], horses (NISP = 94), cattle (NISP = 38), sheep (NISP = 14), goats (NISP = 11), deer (NISP = 169), dogs (NISP = 97), fish (NISP = 116), birds (NISP = 123), frogs (NISP = 1380), and shells (NISP = 90). Preliminary studies have shown that domestic pigs and dogs had already existed at that time.

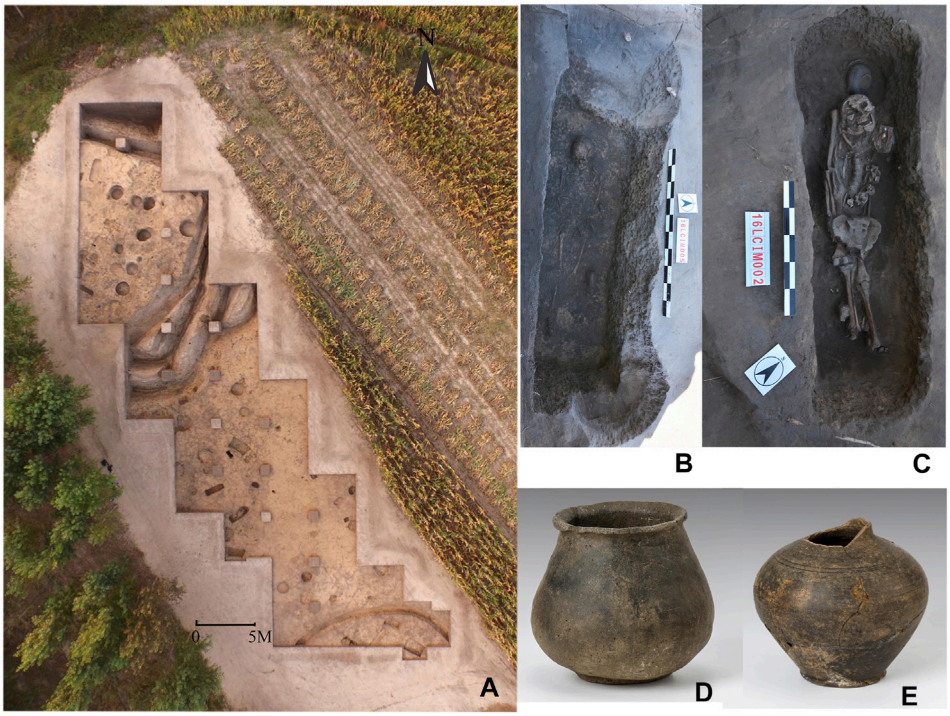

FIGURE 2 | (A) aerial photograph of the excavation area of the Changshan site in 2016 **(B)** picture showing top view of the burial of one Bronze Age individual **(C)** a pottery vessel in the Bronze Age **(D)** picture showing top view of the burial of one Liaojin Dynasties individual **(E)** A pottery vessel in the Liaojin Dynasties.

This study focused on identification of pigs using traditional morphological observations and biometric measurements. The number of pigs unearthed at the site (NISP = 297) accounts for 34.3% of all mammals. To clarify the nature of the pigs at the site, the sizes of the pig teeth, ages of death, and levels of linear enamel hypoplasia (LEH) were also conducted. A total of 73 identifiable specimens of pig bones was unearthed that date to the Bronze Age (NISP), and the minimum number (MNI) of pigs was four; the number of identifiable specimens of unearthed pig bones that date to the Liaojin Dynasties (NISP) was 218, and the minimum number (MNI) of pigs was six. Given the distribution of the bones in pits excavated from different areas of the site, it is likely that more than 10 pigs are represented in the study sample.

Only one lower M3 dated to the Bronze Age measuring 38.06 mm in size, and four lower M3 in the Liaojin Dynasties measuring 41.21, 39.18, 39.98, and 38.54 mm in size are all less or similar to 39.00 mm, which is the current domestic pig standard size (Guan 2008; Luo 2012; Zhang and Julia, 2019), indicating that these pigs were likely domestic pigs. There were certain amounts of linear enamel hypoplasia (LEH) observed in both the Bronze Age and the Liaojin Dynasties, and the incidence of LEH in the Bronze Age was relatively high (Luo 2017). Additionally, eight canine teeth were found, including seven female and one male (Luo 2017). The age of death was mostly found to be in the same range at 18–24 months (Luo 2017), indicating that the past populations obtained meat resources by killing the pigs in the optimum time.

MATERIALS AND METHODS

Sampling Strategy

In this study, 52 bones samples (**Table 1**) were used, including 35 pigs, eight horses, two cattle, two goats, four sheep, and one human. One sample was a pig bone from the Neolithic Age, 20 were from the Bronze Age, including 15 pigs, four horses, and one sheep. The remaining 31 were from Liaojin Dynasties, including 19 pigs, four horses, three sheep, two cattle, two goats, and one human.

Collagen Preparation and Isotopic Measurements

The collagen extraction process primarily refers to the method adopted by Jay and Richards (2005). The surface of bones was cleaned, and 2–3 g samples were obtained. They were then put separately in a 50 ml beaker, and 30 ml of 0.5 M HCl solution was added and soaked at 4°C. The acid solution was replaced every 2 days. When the bone samples were soft with no obvious bubbles on the bone surfaces, the bone samples were washed to a neutral pH with deionised water. The neutral bone samples were then soaked in 0.125 M NaOH solution for 20 h. The samples were washed with deionised water until they had neutral pH levels. The neutral bone samples were soaked in a 0.001 M HCl solution at 70°C for 48 h and then filtered into a test tube while hot to obtain a

TABLE 1 | Isotopic results and sample information for fauna from the Changshan site.

Lab ID.	Context	Species	Period	Element	C (%)	N (%)	C/N	δ^{13}C (‰)	δ^{15}N (‰)
L1	16LCIH004①:1	Pig (Sus)	Liaojin Dynasties	Humerus	22.9	15	1.8	−19.9	4.9
L2	16LCIH004①:2	Pig (Sus)	Liaojin Dynasties	Humerus	42.3	12.9	3.8	−19.3	4.6
L3	16LCIH004①:3	Pig (Sus)	Liaojin Dynasties	Humerus	42.8	14.4	3.5	−20	5.5
L4	16LCIH004①:7	Pig (Sus)	Liaojin Dynasties	Radius	39.1	14	3.3	−20.4	4.3
L5	16LCIH004①:8	Sheep (Ovis)	Liaojin Dynasties	Radius	42.5	14.8	3.4	−20.8	6.3
L6	16LCIH004①:12	Pig (Sus)	Liaojin Dynasties	Femur	41.1	14.7	3.3	−19.4	5.4
L7	16LCIH004①:13	Pig (Sus)	Liaojin Dynasties	Tibia	43.6	14.7	3.5	−18.8	6.3
L8	16LCIH019:1	Pig (Sus)	Liaojin Dynasties	Humerus	43.1	14.6	3.5	−19.6	4.5
L9	16LCIH019:2	Pig (Sus)	Liaojin Dynasties	Humerus	—	—	—	—	—
L10	16LCIH019:3	Pig (Sus)	Liaojin Dynasties	Humerus	40.5	14.4	3.3	−19.7	4.3
L11	16LCIH019:13	Pig (Sus)	Liaojin Dynasties	Tibia	39.9	12.5	3.7	−20.2	6
L12	16LCIH025①:1	Pig (Sus)	Liaojin Dynasties	Tibia	41.1	14.8	3.3	−20.6	4.2
L13	16LCIH025①:3	Sheep (Ovis)	Liaojin Dynasties	Tibia	43.7	15.5	3.3	−17	5.3
L14	16LCIH069①:1	Pig (Sus)	Bronze Age	Radius	39.7	13.7	3.4	−20	3.9
L15	16LCIH069:1	Pig (Sus)	Bronze Age	Humerus	41.9	14.9	3.3	−19.6	4.5
L16	16LCIH069:2	Pig (Sus)	Bronze Age	Humerus	2.5	1.6	1.8	−21.8	—
L17	16LCIH069:3	Pig (Sus)	Bronze Age	Humerus	39.3	14.1	3.3	−19.8	4.4
L18	16LCIH069:11	Pig (Sus)	Bronze Age	Femur	—	—	—	—	—
L19	16LCIH069:12	Pig (Sus)	Bronze Age	Femur	34.6	13.1	3.1	−19.2	5.4
L20	16LCIH069:13	Pig (Sus)	Bronze Age	Femur	16.8	5.5	3.6	−19.2	5.7
L21	16LCIH069:14	Pig (Sus)	Bronze Age	Tibia	38.7	12.4	3.7	−18.9	6.1
L22	16LCIH069:15	Pig (Sus)	Bronze Age	Tibia	—	—	—	—	—
L23	16LCIH069:17	Pig (Sus)	Bronze Age	Tibia	34.7	12.7	3.2	−19.1	5.4
L24	16LCIH072:1	Pig (Sus)	Bronze Age	Humerus	41.8	13.3	3.7	−14	7.2
L25	16LCIH072①:1	Pig (Sus)	Bronze Age	Radius	41.1	15	3.2	−14.1	7
L26	16LCIH074①:1	Pig (Sus)	Liaojin Dynasties	Tibia	38.8	13.8	3.3	−19.4	5.1
L27	16LCIH078①:2	Pig (Sus)	Liaojin Dynasties	Tibia	44.9	14.4	3.6	−19.5	6.4
L28	16LCIH087①:1	Cattle (Bos)	Liaojin Dynasties	Tibia	41.5	14.7	3.3	−12.9	8.1
L29	16LCIG004④:3	Horse (Equus)	Liaojin Dynasties	Femur	40.2	15.2	3.1	−19.3	3.5
L30	16LCIG004⑤:2	Horse (Equus)	Liaojin Dynasties	Tibia	41.4	14.2	3.4	−20.3	3.8
L31	16LCIG005①:1	Pig (Sus)	Bronze Age	Humerus	39.5	14.5	3.2	−20.8	5.9
L32	16LCIG005②:3	Horse (Equus)	Bronze Age	Tibia	43.1	15.4	3.3	−16.5	5.2
L33	16LCIG006①:1	Pig (Sus)	Liaojin Dynasties	Tibia	42	14.7	3.3	−20.2	4.9
L34	16LCIG006③:8	Goat (Capra)	Liaojin Dynasties	Radius	40.4	14.3	3.3	−21.5	5.9
L35	16LCIG006③:9	Sheep (Ovis)	Liaojin Dynasties	Radius	41.1	14.5	3.3	−20.6	5.4
L36	16LCIG006③: 12	Pig (Sus)	Liaojin Dynasties	Tibia	43.4	15	3.4	−20.9	5.1
L37	16LCIG007①:2	Pig (Sus)	Liaojin Dynasties	Radius	40.1	14.6	3.2	−19.9	4.9
L38	16LCIG007①:3	Pig (Sus)	Liaojin Dynasties	Tibia	43.1	15	3.4	−18.9	5.6
L39	16LCIG007②:1	Horse (Equus)	Liaojin Dynasties	Tibia	42.2	15.8	3.1	−15.2	8
L40	16LCIG007③:1	Cattle (Bos)	Liaojin Dynasties	Humerus	42.8	14.9	3.4	−19.9	3.8
L41	16LCIG008②:3	Pig (Sus)	Liaojin Dynasties	Radius	42.5	14.6	3.4	−20.1	4.1
L42	16LCIG008②:4	Horse (Equus)	Liaojin Dynasties	Radius	41.8	14.7	3.3	−19	4.2
L43	16LCIT0305③:1	Pig (Sus)	Neolithic Age	Humerus	—	—	—	—	—
L44	16LCIT0604①:1	Pig (Sus)	Liaojin Dynasties	Tibia	40.8	14.3	3.3	−19.7	6.2
L45	16LCIT0902①:1	Goat (Capra)	Liaojin Dynasties	Radius	42.8	15.4	3.3	−19.1	6.4
L46	16LCIT1002②:1	Horse (Equus)	Bronze Age	Radius	40.7	14.5	3.3	−19.3	4.8
L47	16LCIT1002②:3	Pig (Sus)	Bronze Age	Femur	41	14.6	3.3	−20.4	6.5
L51	16LCIH007①:2	Human (Homo)	Liaojin Dynasties	Scapula	41.9	15.1	3.2	−13.9	10.3
L52	16LCIH069:10	Pig (Sus)	Bronze Age	Femur	—	—	—	—	—
L53	16LCIH053:1	Horse (Equus)	Bronze Age	Femur	36.1	12	3.5	−19.5	3.9
L54	16LCIH069:19	Sheep (Ovis)	Bronze Age	Tibia	35.9	11.5	3.6	−19.7	5
L55	16LCIH053:2	Horse (Equus)	Bronze Age	Talus	4.5	105.3	0.1	−20.3	4.9

Note: Bronze Age (c. 2000–256 BC); Liaojin Dynasties (907–1234 AD).

collagen solution, and then placed in a freeze dryer for 48 h to obtain collagen.

The determinations of the collagen carbon and nitrogen isotopes were completed in the stable isotope analysis laboratory of the Institute of Geology and Geophysics, Chinese Academy of Sciences. An elemental analyser was combined with a gas isotope mass spectrometer EA-IRMS to complete the tests. The Delta V model of mass spectrometer was used. The organic carbon standards used for determining the C and N contents were graphite and urea, respectively, and the standard substance used for nitrogen was glycine. In the process of sample testing, one tin cup blank and one standard substance were added for every six sample test sequences. The standard substances used for the carbon isotope measurements were GBW04407 (δ^{13}C = −22.43%) and IVA urea

($\delta^{13}C$ = −49.1%), and the standard substances used for the nitrogen isotope measurements were USGS64 ($\delta^{15}N$ = 1.76%) and USGS65 ($\delta^{15}N$ = 20.68%). The measured sample values were corrected using a two-point calibration method. The carbon values were presented relative to the value of the international standard VPDB, and the nitrogen values were presented relative to that of the international standard Air-N_2 (**Table 1**).

RESULT

Results of Stable Isotope Testing

As shown in **Table 1**, L9, L18, L22, L43, and L52 failed in collagen extraction. Generally, the other bone collagen discussed below had an average carbon content of 38.4 ± 8.9%, with a range of 2.5–44.9%, an average nitrogen content of 15.7 ± 13.5%, with a range of 1.6–105.3%, and atomic C/N ratios in the range of 0.1–3.8, unlike those of modern bones (41.0% carbon content, 15.0% nitrogen content, and 2.9–3.6 C/N ratio) (DeNiro 1985; Ambrose 1990). This suggested that some samples could not be used for stable isotope analysis.

After careful consideration of the three standards, the atomic C/N ratios of L1, L2, L11, L16, L21, L24 and L55 were out of the range 2.9–3.6 (DeNiro 1985). Thus, these samples could not be studied further. Finally, the remaining samples (n = 40) retained their *in vivo* isotopic signatures.

Isotopic Results of Human and Animals

A scatter plot of the isotopic data from the human and animals is depicted in **Figure 3**. One human had high $\delta^{13}C$ value (−13.9%) and $\delta^{15}N$ value (10.3%), suggesting that the human consumed large quantity of C_3/C_4-based animal protein (Zhang et al., 2003; Pei et al., 2008; Hou et al., 2021). The $\delta^{13}C$ values for all the fauna (n = 39) ranged from −21.5% to −12.9%, with an average of −19.2 ± 1.8‰, while the $\delta^{15}N$ values ranged from 3.5 to 8.1‰, with an average of 5.3 ± 1.1%, reflecting a diet mainly composed of large quantities of C_3-based plants (Ambrose and Norr 1993; Hu 2002).

As shown in **Figure 3**, the $\delta^{13}C$ values of all pigs ranged from −20.9% to −14.1%. The average $\delta^{13}C$ value (−19.6 ± 1.3%, n = 24) suggested that they predominately consumed C_3-based diets (Hu et al., 2009). However, the wide variation of the $\delta^{13}C$ values suggested that these pigs had diverse diets, with some consuming substantial C_4-based diets (Hu et al., 2006; Guo et al., 2011), that is, one pig (L25: −14.1%, 7.0%) in the Bronze Age, also consumed a large quantity of C_4-based food. The pig $\delta^{15}N$ values ranged from 3.9 to 7.0% with an average of 5.2 ± 0.9% (n = 24), suggesting that pigs mostly consumed plants. Sheep (range −20.8‰ to −17.0% and range 5.0–6.3%, means −19.5 ± 1.8% and 5.5 ± 0.6%, respectively, n = 4), goats (L34: −21.5%, 5.9%; L45: −19.1%, 6.4‰; n = 2), and horses (range −20.3% to −15.2% and range 3.5–8.0%, means −18.4 ± 1.9% and 4.8 ± 1.5%, respectively, n = 4) also show isotopic patterns similar to pigs, reflecting a similar diet.

Notably, two cattle (L34: −12.9%, 8.1%; L45: −19.9%, 3.8%; n = 2) have a different isotopic pattern. As shown in **Figure 3**, L45 had a diet similar to most of the above animals. However, L34's diet might have been mainly composed of a large quantity of C_4-based food, such as C_4-based fodder (Makarewicz 2017).

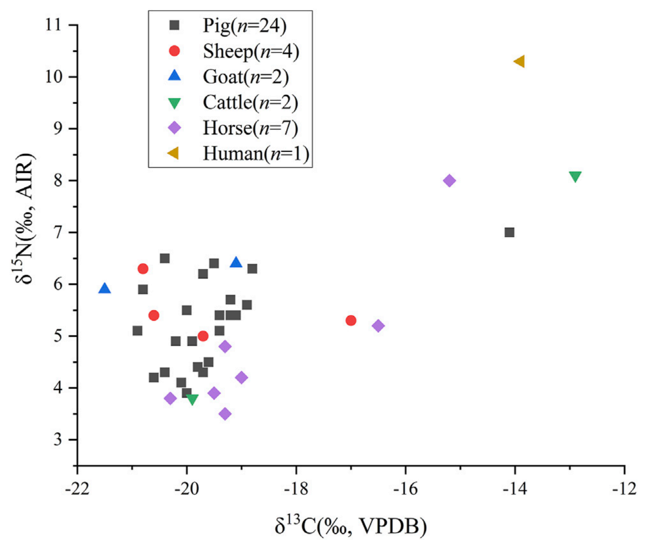

FIGURE 3 | Scatter plot of the stable isotopes of animal bones from the Changshan site.

DISCUSSION

Diet of Animals in the Bronze Age

The $\delta^{13}C$ and $\delta^{15}N$ values scatter plots of animal bone collagen in the Bronze Age are shown in **Figure 4**. The carbon and nitrogen values of all the data are concentrated (pigs: −19.1 ± 1.9%, 5.4 ± 1.0%, n = 9; horses: −18.5 ± 1.4%, 4.7 ± 0.5%, n = 3; sheep: −19.7%, 5.0%, n = 1), and the nitrogen values fall within the trophic level of herbivores (Ambrose and Norr 1993). Overall, sheep, horses, and pigs predominately relied on a diet of C_3 plants, probably from plant leaves and C_3-typed grasses. Meanwhile, one horse (L32: −16.5%, 5.2%) had high $\delta^{13}C$ values, reflecting a C_3/C_4-based diet with a small amount of C_4-based fodder. In addition, one pig (L25: −14.1%, 7.0%) had higher $\delta^{13}C$ and $\delta^{15}N$ values among these animals, indicating that the pig may have consumed C_4-based fodder, including millet and/or millet by-products.

Since the Holocene, the vegetation in northern China has been dominated by C_3 plants with low $\delta^{13}C$ average values (−26.5%) (O' Leary 1981; Ambrose 1991; Guan et al., 2007). Millets comprised a vast majority of C_4 plants belonging to the C_4 category with a high $\delta^{13}C$ average (−12.5‰), which were cultivated during the Neolithic period in northern China (Dong et al., 2016). The $\delta^{13}C$ values of the heavy millet consumers are mostly high in northern China, with a value of ≥−12‰ (Barton et al., 2009). At the Changshan site, the ubiquity of foxtail millet (*Setaria italica*, n = 25) and common millet (*Panicum miliaceum*, n = 33) are 15% and 12%, respectively (Chen 2019), indicating that millet-based agriculture was not an important subsistence strategy for populations residing in the East Liao River Basin in the Bronze Age.

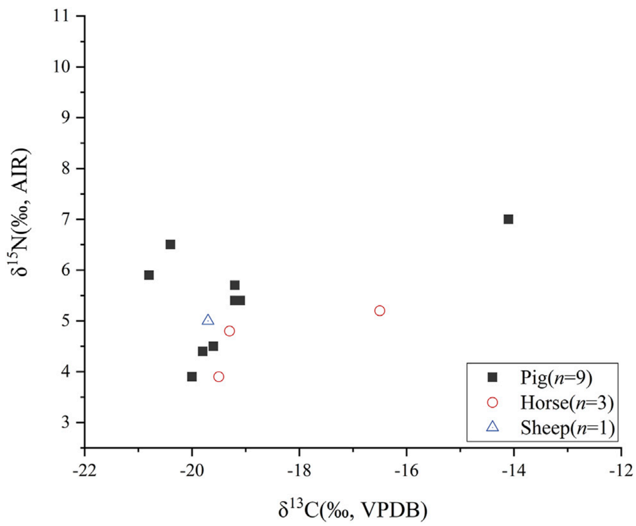

FIGURE 4 | Scatter plot of the stable isotopes of animal bones from the Changshan site during the Bronze Age.

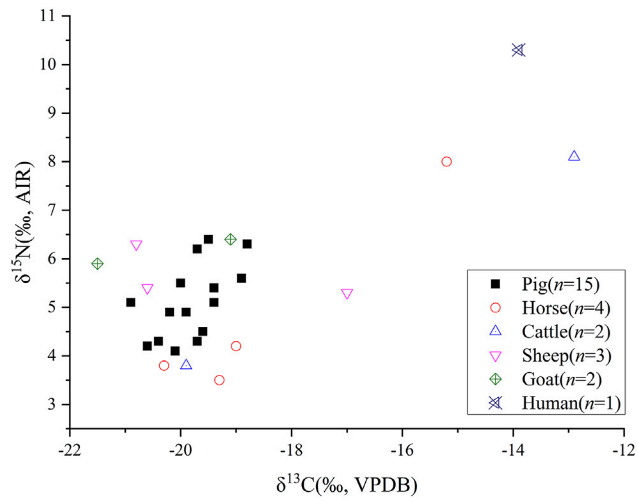

FIGURE 5 | Scatter plot of the stable isotopes of animal bones from the Changshan site during the Liaojin Dynasties.

Thus, the diet of above animals shows that livestock management strategies are dominated by a free-range economy based on wild plants, with C_4-based fodder representing a minor proportion of feeding strategy in East Liao River Basin during the Bronze Age.

Diet of Human and Animals in the Liaojin Dynasties

The scatter plots of $\delta^{13}C$ and $\delta^{15}N$ values of animal bone collagen from the Liaojin Dynasties are shown in **Figure 5**. The carbon and nitrogen values of pigs (−19.8 ± 0.6%, 5.1 ± 0.7%, n = 15), sheep (−20.7 ± 0.1%, 5.9 ± 0.5%, n = 2), goats (−20.3 ± 1.2%, 6.2 ± 0.3%, n = 2), one cattle (L40: −19.9%, 3.8%), and most horses (−19.5 ± 0.6%, 3.8 ± 0.3%, n = 3) showed that these animals predominately relied on a diet of C_3 plants. Herbivores such as sheep, horses, and goats have low $\delta^{13}C$ and $\delta^{15}N$ values, forming an isotopic baseline for understanding the wild ecosystem, which were likely dominated by C_3 plants and C_3 grasses (e.g., Guan et al., 2008).

One sheep (L13: −17.5%, 3.0%), and one horse (L39: −15.2%, 8.0%) had a slightly high $\delta^{13}C$ values, which might relate to more C_4 food, including C_4-based fodder, in their diet. The cattle of L28 had the highest $\delta^{13}C$ value (−12.9%) and high $\delta^{15}N$ value (8.1%), indicating that the cattle with a different feeding strategy consumed a large amount of C_4-based fodder, such as millets and millet by-products (Makarewicz 2017).

The high $\delta^{13}C$ value (−13.9‰) and $\delta^{15}N$ value (10.3‰) in human bone collagen suggested that the individual consumed a large amount of C_4-based animal protein. The $\delta^{13}C$ value was also positively related to the mean value for most animals (−20.0 ± 1.3%, n = 25; excluding the cattle of L28: −12.9%, 8.1%). This was probably because this person also consumed animal protein with high $\delta^{13}C$ values.

Although millet agriculture developed in the East Liao River Basin during the Liaojin Dynasties, it just only used as an auxiliary subsistence strategy. For example, at the Changshan site, the ubiquity of foxtail millet (n = 123) and common millet (n = 177) are 22% and 25%, respectively during this period (Chen 2019). C_4-based food, such as millet, meat, and egg, might have been the commodity provided to populations by the Central Plains in the Liaojin dynasties, as described in the Chapter of Shi Huo Zhi—Liao Shi 辽史-货志 and Shi Huo Zhi—Song Shi 宋史-食货志 (Cui et al., 2021). According to the book, millet was transported to the capital of Liao, Chifeng, which was close to the current Changshan site (Liang and Bao 2008). Meanwhile, some immigrants from the agricultural area might have lived in this area for a short period (Liang and Bao 2008), as described in the Chapter of Shi Huo Zhi—Jin Shi 金史-食货志. However, as more human bones are currently unavailable at the Changshan site, we cannot reconstruct human diet and subsistence.

Based on the diet of above animals, we can conclude that livestock management strategies used at that period were like those used in the Bronze Age.

Undiversified Pig Management Strategy Over a Long Term

Generally, a similar diet was present for animals, especially the pigs, in the Changshan site over a long period, indicating that a similar management strategy for animals existed in this region.

Notably, the number of animals of each species ($n \leq 3$) was small, especially domesticated animals, such as sheep, goats, cattle, and horses, during both the Bronze Age and the Liaojin Dynasties. Thus, we would not be able to further discuss the relationship between animal dietary patterns and the management strategy over a long period. However, the number of pigs during both periods (the Bronze Age, n = 9; the Liaojin Dynasties, n = 15) is sufficient for discussing the pig management strategy in this region. Meanwhile, to gain a better understanding of pig management strategies at the Changshan site, the published isotopic data from near this area and

TABLE 2 | Summary of isotopic results for Pigs from the previous published data in different region, China.

Region	Site	Period	*n*	δ^{13}C ± SD (‰)	δ^{15} N ± SD (‰)	Reference
Dongliao River	Changshan	Bronze Age	9	−19.1 ± 2.0	5.4 ± 1.0	This study
		Liaojin Dynasties	15	−19.8 ± 0.6	5.1 ± 0.7	
	Wanfa Bozi	Bronze Age	21	−21.3 ± 0.7	4.4 ± 0.5	Guan et al. (2007)
		Weijin Dynasties	5	−20.8 ± 0.3	4.7 ± 0.5	
Xiliao River	Xinglonggou	Bronze Age	8	−10.1 ± 4.4	7.5 ± 1.7	Zhang et al. (2017)
Central Plains	Xinzhai	Bronze Age	11	−8.5 ± 1.1	6.2 ± 0.9	Zhang et al. (2015)
	Erlitou	Bronze Age	22	−10.4 ± 2.7	7.3 ± 1.2	Wu et al. (2007)
	Taosi	Bronze Age	17	−6.8 ± 1.3	7.5 ± 0.6	Chen et al. (2012)
	Zhangdeng	Bronze Age	18	−7.5 ± 1	7.6 ± 0.5	Hou et al. (2013)

Note: Bronze Age (c. 2000–256 BC); Weijin Dynasties (220–420 AD); Liaojin Dynasties (907–1234 AD).

the Central Plains, dating from the Bronze Age (c. 2000–256 BC) to the Liaojin Dynasties 907–1234 AD), is summarized in **Table 2**, and is showed in **Figure 6**.

As shown in **Figure 6**, there was no shift in the δ^{13}C and δ^{15}N values of pigs from the Bronze Age (−19.1 ± 2.0%, 5.4 ± 1.0%, n = 9) to the Liaojin Dynasties (−19.8 ± 0.6%, 5.1 ± 0.7%, n = 15), indicating that they had a similar diet with predominantly C_3 plants and might have been fed by a similar free-range strategy. Furthermore, the independent t-test statistical analysis of the difference of mean δ^{13}C and δ^{15}N values showed non-significant (δ^{13}C: p = 0.225; δ^{15}N: p = 0.434, respectively) results. Additionally, the pigs in the Wanfa Bozi site (**Figure 1**), which was located close to the Changshan site dating back to the Bronze Age and the Weijin Dynasties (220–420 AD), presented an isotopic pattern (Guan et al., 2007) similar to that of the Changshan site (**Table 2** and **Figure 6**). This confirmed that there was no change in the pig management strategy in the East Liao River Basin over a long period. As mentioned in the Introduction section, pig management strategies in southern China also adopted a free-range style (Dong and Yuan 2020), similar to that of the Changshan site.

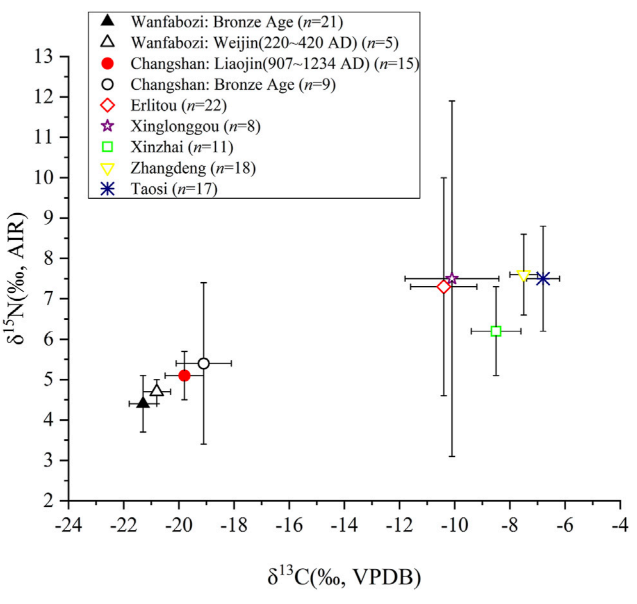

FIGURE 6 | Error bar chart for this study and previous published data in different region, China.

However, the pig with a different isotopic pattern (**Table 2** and **Figure 6**) was presented in the West Liao River Basin and the Central Plains in the Bronze Age (**Figure 1**). Both areas were dominated by millet agriculture (Dong et al., 2016), and pigs mainly consumed millet-based food, showing high δ^{13}C values. As demonstrated in **Table 2** and **Figure 6**, pigs in the Central Plains, such as the Taosi (Chen et al., 2012), Erlitou (Wu et al., 2007), Zhangdeng (Hou et al., 2013), and Xinzhai sites (Wu et al., 2007; Zhang and Zhao, 2015; Dai et al., 2016), as well as in the West Liao River Basin (Liu et al., 2012), such as Xinglonggou site (Zhang et al., 2017), had higher δ^{13}C and δ^{15}N values than those of the pigs in the East Liao River Basin, such as the Changshan and Wanfa Bozi sites. This indicated that such pigs predominately relied on a diet of millet-based food. Since the spread of millet agriculture into the middle reaches of Yangtze River (Dong et al., 2016; Hu 2021), the diet of pigs (δ^{13}C: −13.4 ± 3.2%, δ^{15}N: 7.1 ± 1.2%, respectively, n = 28) at the Qinglongquan site (c. 3000–c. 2200 BC) reflected millet-based food to some extent (Guo et al., 2011; Chen et al., 2015).

Thus, what is the reason for using different pig management strategies in different areas? In the East Liao River Basin from the Bronze Age to the Liaojin Dynasties, the past populations in Changshan area made their living in a stable climate with warm and moist grasslands and/or forests and with abundant natural resources, such as plants, wild animals, and fishes, which were adequate sources of food to them (Chen 2007). Similar conditions also existed in southern China over a long period (e.g., Dong and Yuan 2020; Hongo et al., 2021). Although pigs provided meat resources, the driving force for intensive pig feeding was weak in these areas, leading to the existence of free-range pigs. On the contrary, multiple lines of evidence have revealed that millet-based agriculture became a dominant subsistence economy in the West Liao River Basin, the Central Plains, and the middle reaches of Yangtze River in the Neolithic Periods (Dong et al., 2016). Thus, the past populations used pigs for meat resources, and pigs were fed based on the millet-based agriculture (Hou 2019).

Finally, the East Liao River Basin had a stable climate and abundant natural resources, leading to a steady subsistence pattern over a long period, with pigs being freely fed based on the wild ecosystem.

CONCLUSION

Based on the stable isotope analysis of human and animal bones from the Changshan site, the following conclusions can be drawn:

1) Most animals had a diet composed of C_3 plants. A free-range management strategy was used based on the wild ecosystem of the Changshan site. However, human and a few animals consumed a certain amount of C_4 food, such as millet-based food.
2) No dietary shift was observed for most animals, especially pigs from the Bronze Age to the Liaojin Dynasties, indicating an undiversified pig management strategy in the East Liao River Basin.
3) The East Liao River Basin had a stable climate and abundant natural resources, leading to a similar pig management strategy over a long period.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding authors.

AUTHOR CONTRIBUTIONS

LH, XL, LB and CW designed the study. LH, XL, YG, CW and HL conducted the study. LH, XL, LB and CW wrote an initial version of the manuscript. All co-authors reviewed and made modifications to the final version of the manuscript.

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