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Plant exploitation and subsistence patterns of the Mesolithic in arid China: New evidence of plant macro-remains from the Pigeon Mountain site

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The nature of the Mesolithic in China has not been studied much due to the few well-context sites discovered and excavated during this period. The situation also restricts the understanding of human subsistence in the Mesolithic period in China, especially in the arid region. The present paper reports the flotation results at Locality 10 of the Pigeon Mountain site in Northwest China. Ten species of plants belonging to six families were identified, dominated by *Agriophyllum squarrosum* and *Artemisia sieversiana*. No firm evidence proves the domestication. Combined with the lithic artefacts in QG10, ancient people could utilize plant resources by constructing or expanding the food spectrum. It is the first systematic archaeobotany work in the Paleolithic site of Northwest China. The result reminds us that the enhanced utilization of wild plant resources is a vital subsistence for Mesolithic people in arid regions.

KEYWORDS

Pigeon Mountain site, macro-remains, ancient plant utilization, arid and semi-arid, Northwest China

Introduction

The Paleolithic period, also known as the Old Stone Age, was a time in human history marked by the development of stone tools. On the other hand, the Neolithic period was characterized by the emergence of agriculture and polished stone tools (Fagan, 2010). The transition from the Paleolithic to Neolithic was marked by the domestication of animals, manufacture of pottery, and intensified utilization of plants (Liu and Chen, 2017). Due to climate fluctuations, ancients frequently adjusted their subsistence strategies by equipping them with portable and flexible composite tools made of organic material and microblades, grinding stone tools, and pottery (Price, 1987). These tools strengthened the ability of ancient humans to hunt animals and exploit plant resources. The trajectory became significant during the Mesolithic. The ancients gradually increased the utilization of plant resources, such as seeds and fruits. Plant exploitation and subsistence patterns during these periods have been inferred from the study of plant macro-remains or the physical remains of plants

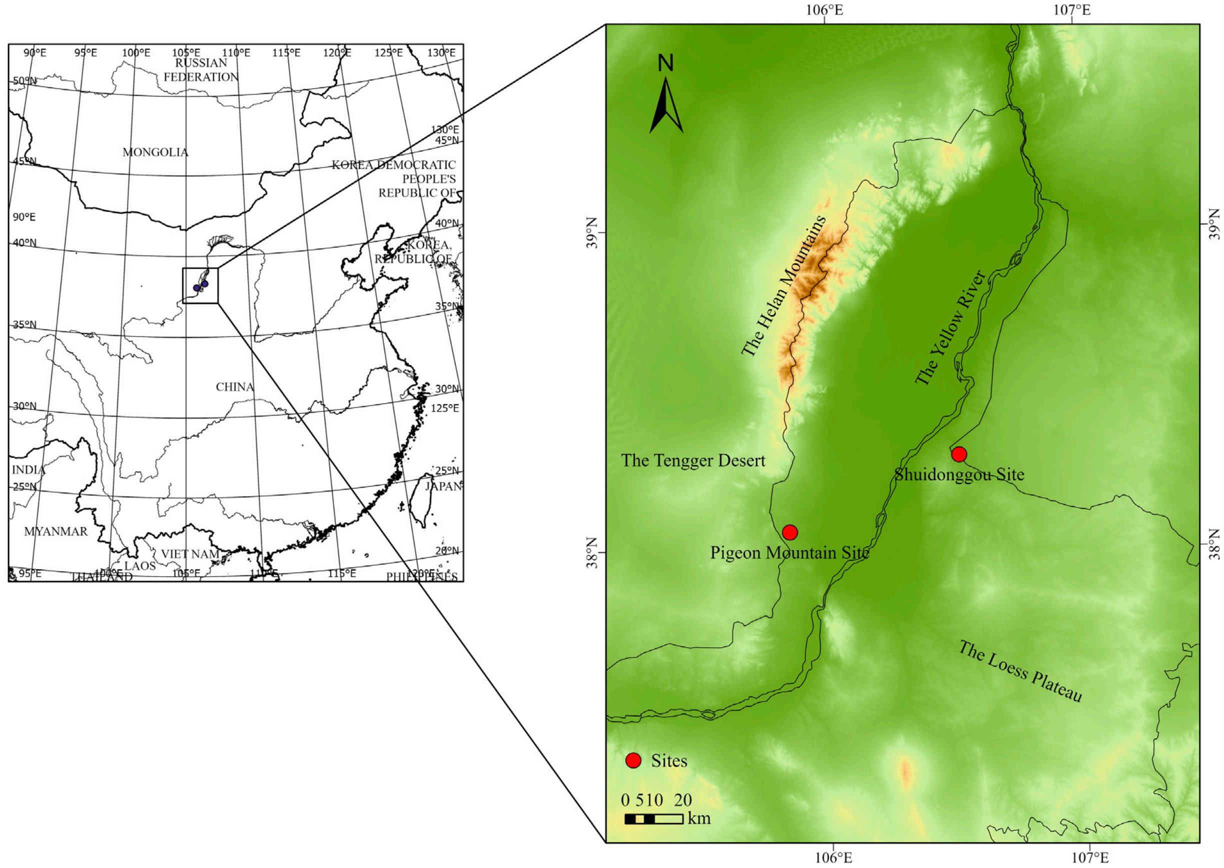

FIGURE 1
Geographical location of the Pigeon Mountain site.

that can be analyzed and identified. These remains include seeds, fruits, nuts, and other plant parts preserved in the archaeological record.

In the 1960s and 1970s, Binford and Flannery proposed the "Broad Spectrum Revolution" concept, which indicates that hunter–gatherers significantly improved their ability to adapt to the environment by expanding their diets in the late Paleolithic (Binford, 1968; Flannery, 1973). Climate change resulted in worse environmental conditions, and the quantity of food resources decreased drastically. Ancient people had to exploit more kinds of food and rely more on plant resources than before in this situation. Though the climate steadily warmed up after the Last Glacial Maximum, some cooling events still occurred irregularly (Lu, 1999; Lu, 2006). The transitions occurred at different times in different places worldwide and were called the Mesolithic period someplace. In Europe, using wild plant food was accepted as a norm for the Mesolithic period (Zvelebil, 1994). However, the transition dynamics of the Mesolithic period in China are still unclear. The main reason is few archaeological sites in the Mesolithic period, ranging from terminal Pleistocene to early Holocene about 13–9 ka BP, have been discovered and systematically excavated. Most discovered sites include the Longwangchan site (The Institute of ArchaeologyCASS, 2021) in Shaanxi, the Xiachuan site (Du, 2021), the Shizitan site (Liu et al., 2011) in Shanxi, Yujiagou in Hebei, the Lijiagou site (Wang et al., 2011) in Henan, and the Donghulin site (Zhao et al., 2020) in Beijing, concentrated in North and Northeast China.

The present paper provides the latest utilization of plant resource evidence from the Pigeon Mountain site, a Mesolithic site in China's arid and semi-arid regions, mainly in Northwest China. The research aims to explore the types of plants and subsistence patterns in the Pigeon Mountain site and shed light on the strategy and subsistence of people during the Mesolithic period in arid China.

Archaeological background and study sites

Before the emergence of agriculture and permanent settlement, seasonal variations in precipitation and temperature challenged the survival of ancient people in higher-latitude areas in the northern region of China. China's vast territory is described as the Three Steps or the Three Gradient Terrains based on the average altitude from west to east and the relief amplitude (Guan et al., 2020). The first gradient terrain is the Qinghai–Tibetan Plateau. The second gradient terrain includes the Inner Mongolian Plateau, Xinjiang Autonomous Region, Yunnan–Guizhou Plateau, Loess Plateau, and Sichuan Basin. The third gradient terrain comprises plains and hills

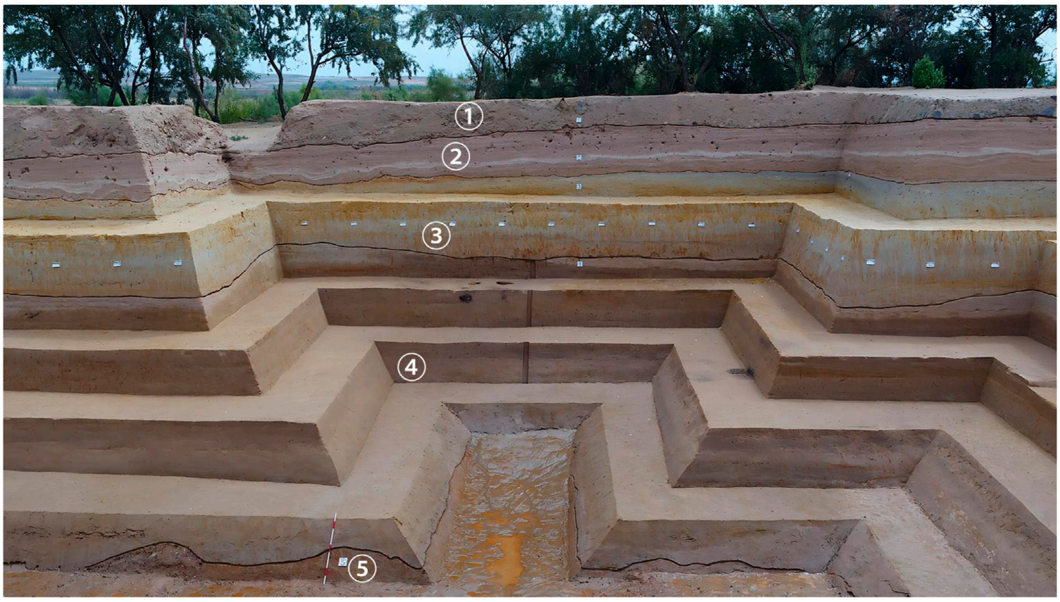

FIGURE 2
Stratigraphic profile of QG10.

below 500 m above the sea level (Guan et al., 2020). Most Paleolithic–Neolithic sites are found on the second- and third-gradient terrain where the environment is suitable for animal–plant domestication, permanent occupation, and human survival. Figure 1 shows the geographical location of the Pigeon Mountain site, which is in Northwest China, characterized by an arid and semi-arid climate.

The Pigeon Mountain site (QG) is located in northwest of Qingtongxia City, Ningxia Hui Autonomous Region, China. It is composed of 15 localities. In the literature, the site is either referred to as "Pigeon Mountain Loc. 10" or it is Chinese pinyin equivalent, i.e., "Gezishan Loc. 10" (Zhang et al., 2022). In the 1990s, QG3 and QG4 were excavated by a joint team of Chinese and American scholars. Evidence of microblades, grindstones, and flakes had been yielded (Elston et al., 1997). These remains provide valuable insights into the subsistence patterns of those who lived there during these periods. The ^{14}C age indicates that it is a Mesolithic period site less commonly discovered in the arid region. Meanwhile, the site is situated in a transition zone between the northwest desert and the Loess Plateau, with a presently mid-temperate continental climate and proximity to the edge of the East Asian monsoon climate zone (Madsen et al., 1996). The mean annual temperature and precipitation are approximately 8.5°C and 260 mm, respectively. The frost-free period is 176 days, the annual sunshine is 2,955 h, and the temperature difference between day and night is significant (Madsen et al., 1996).

The locality 10 of the Pigeon Mountain site (known as QG10, N38°03′33.1″, E105°50′30.3″, altitude ca. 1,200 m) is located on the foothills of the Helan Mountains and the southeast edge of the Tengger Desert, which is about 20 km from Qingtongxia City, Ningxia Hui Autonomous Region, China (Madsen et al., 1996). It is the most important locality in the site complex because of its rich discoveries. QG10 was discovered in the 1990s. However, just sporadic artifacts were collected at that time. In 2013, the Institute of Vertebrate Paleontology and Paleoanthropology, Chinese Academy of Sciences (IVPP-CAS), and the Ningxia Institute of Cultural Relics and Archaeology launched a new investigation in this region. Two new localities were discovered: QG14 and QG15 (Guo et al., 2019). From 2014 to 2017, a formal excavation was conducted at QG10. The new excavation of QG10 unearthed multiple sets of archaeological data with a well-stratigraphic context. This work provides a reliable chronological framework for site research and an opportunity to explore ancient humans' technological adaptation, resource utilization, and environmental adaptation behavior in the desert fringe area. Latest 14C dating display the excavated area covers c. 200 m^2 and reaches a depth of c. 3.5 m (Madsen et al., 1998). The map in Figure 2 shows the QG10 stratigraphic sequence comprising five geological layers from 1 on the top to 5 at the bottom.

Three archaeological horizons were identified in layers 2, 3, and 4 separately. They were named CL1 in Layer2, CL2 in Layer3, and CL3 in Layer4. CL3 yielded the richest archaeological assemblage, including architectural structures, hearth, grinding discs, grinding rods, typical amphibians, Helan pointed implements, animal skeletons, macro-remains, micro-remains, and small ornaments made of ostrich egg skins, especially animal skeletons, macro-remains, micro-remains, fire ponds, architectural structures, and others remains indicating that ancient humans exploited more diverse food resources, widening their recipe, closely related to the Broad Spectrum Revolution and society complexities increased.

A total of 361 starch grains and a small amount of plant organ debris were found in 19 stone artifacts from CL2 and CL3. The starch grains include Triticeae, Panicoideae, possibly Fagopyrum, beans (Fabaceae), acorns (Quercus), possibly Typha, Dioscorea or Fritillaria, underground storage organs of other plants, lotus seed and a small number of unidentifiable starch granules and broken

TABLE 1 Soil sample record of Locality 10.

Sample background	CL1		CL2		CL3		Total	
	Liter	Number	Liter	Number	Liter	Number	Liter	Number
Layer	1,640	164	3,765	379	5,078	476	10,483	1,019
Remains	0	0	456	26	2,623	83	3,079	109
Total	1,640	164	4,221	405	7,701	559	13,562	1,128

TABLE 2 Radiocarbon age for the seed in this study.

Lab code	Sample type	^{14}C date (BP)	Calibrated age (cal. BP)	
			1σ (68%)	2σ (95%)
Beta-450602	Seed	10400 ± 30 BP	12395–12225	12410–12120
			12215–12155	

granules. Among them, grasses occupy an absolute advantage, while legumes, nuts, and tubers account for a smaller proportion (Guan et al., 2020). More than 2,000 animal remains were unearthed from CL3. In decreasing order of the identified specimens, animal skeletons are represented by *Lepus* sp., *Equus przewalskyi*, *Procapra przewalskii*, *Vulpes* sp., and Cervids (Zhang et al., 2022).

Materials and methods

During the 2016–2017 field season, two systematic samplings were carried out from 1,128 soil samples, and 13,562 L was collected and floated at CL1, CL2, and CL3 of T5 at the QG10 based on Table 1.

Conducting flotation in the current study has been an effective way of developing subsistence knowledge in a specific region and time. The interpretations and limitations of the data are contextualized based on the type and size. The flotation for extracting the samples was carried out on the Pigeon Mountain site. The flotation samples were sent to the Laboratory of Paleo-ethnobotany, Institute of Archaeology, Chinese Academy of Social Sciences, for identification and analysis after drying in the local shade. The primary method for identifying carbonized plant seeds is to compare the samples unearthed from the archaeological site with the existing species based on researchers' experience and refer to the relevant atlas. At counting, the seed fragments with less than 50% of the seed sizes were omitted. The key to seed identification is its shape and size. The method was favorable for the current study to avoid artificial inflation of the total and follow the principle of the minimum number of samples. The morphology of seeds varies greatly depending on the family and genus they belong to, but there is also the phenomenon that the same plant produces seeds of different shapes. More accurate judgments can be made based on experience and comparison when classifying and identifying. Size is one of the most obvious characteristics of seeds and can be expressed by length, width, and thickness.

In the laboratory, wood charcoal specimens were fractured manually with a razor blade along the three anatomical planes (transverse, radial longitudinal, and tangential longitudinal) and were analyzed under a Nikon LV150 reflected-light bright/darkfield microscope at magnifications of ×50, ×100, ×200, and ×500. Identifications were checked by comparison to wood anatomy atlases (Cheng et al., 1992) and specimens held in the modern microscopic wood anatomy slide reference collection of CASS. A Quanta 650 SEM was used to observe finer anatomical details and to take photos. The description of wood anatomical features follows the definitions given in the published literature (IAWA Committee, 1989; IAWA Committee, 2004; Schweingruber, 1990).

Results

To get an absolute age of the recovered macro-remains, the research focused on 30 seeds of *Agriophyllum squarrosum* from CL3, with a 95% confidence interval of the calibrated ages bounded between 12410 and 12120 Cal BP. Table 2 shows the calibration of radiocarbon age to calendar years with a probability of 95%.

The 10 species of plants belonging to six families were identified (Figure 3): *Agriophyllum squarrosum* (Figure 3A), *Corispermum declinatum* (Figure 3B), *Kochia scoparia* (Figure 3C), *Salsola collina* (Figure 3D), *Artemisia sieversiana* (Figure 3E), *Poa annua* (Figure 3F), *Sclerochloa dura* (Figure 3G), *Allium mongolicum* (Figure 3H), *Viola verecunda* (Figure 3I), and *Lagopsis supina* (Figure 3J).

The average weight of charcoal >1 mm contained in each flotation sample (10 L of each) is 0.038 g, while CL2 and CL3 contain 0.052 and 2.48 g, respectively, as shown in Figure 4. Concerning the three types of relic units, the average number of charcoals and seeds unearthed (each 100 L soil samples) in outlines and holes is the smallest. In contrast, the hearth contains the highest number of charcoals and seeds. In consideration of the weight of charcoals, outlines only yield about

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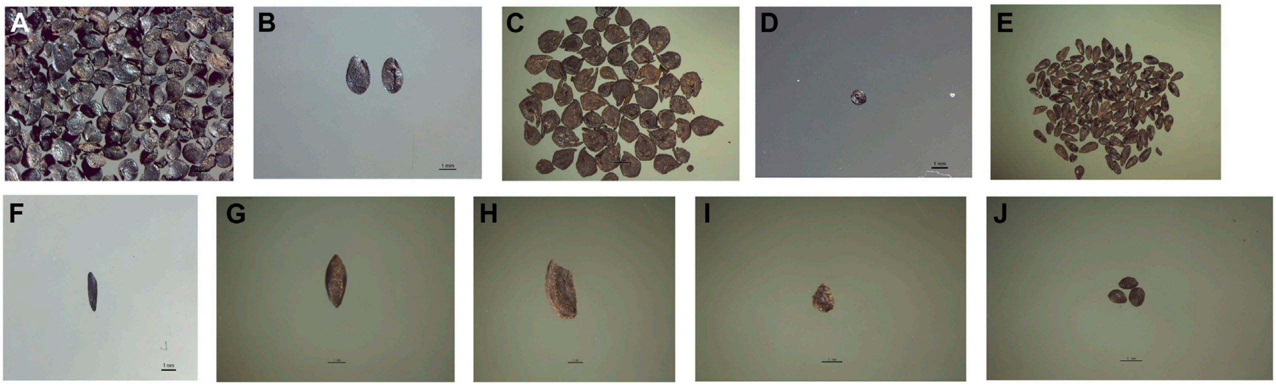
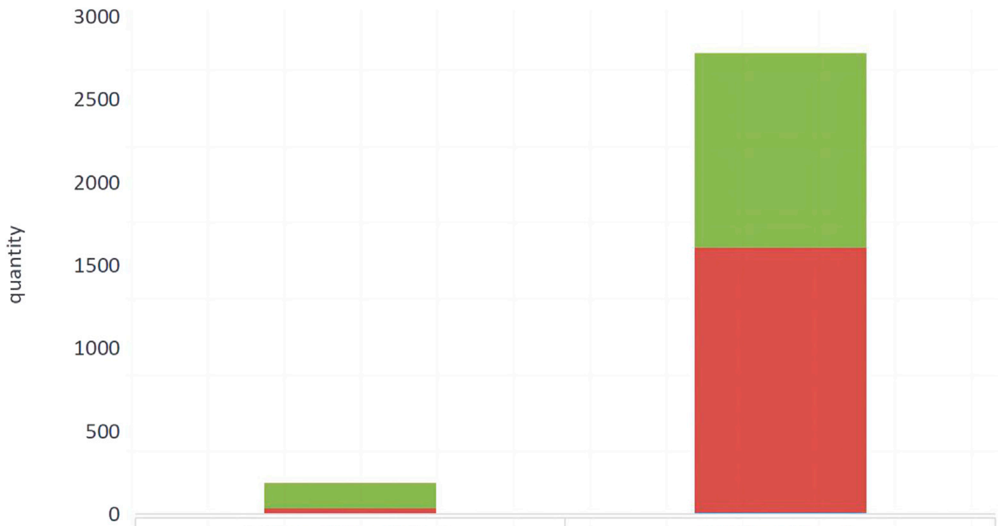


FIGURE 3
Seeds discovered from QG10: **(A)** *Agriophyllum squarrosum*; **(B)** *Corispermum declinatum*; **(C)** *Kochia scoparia*; **(D)** *Salsola collina*; **(E)** *Artemisia sieversiana*; **(F)** *Poa annua*; **(G)** *Sclerochloa dura*; **(H)** *Allium mongolicum*; **(I)** *Viola verecunda*; **(J)** *Lagopsis supina*.



	＞1mm charcoal（g）	number of seeds
hole	151.86	1171
hearth	27.43	1592
outline	4.73	10

FIGURE 4
Comparison diagram of charcoal weight and plant seed quantity per 100 L soil sample unearthed in different relic phenomena, PM.

one-fifth of that unearthed in the hole. This may be related to the different functions of the remains.

Compared to the types of carbonized plant seeds unearthed from most Neolithic and historical, archaeological sites, the types of plant seeds unearthed from the Pigeon Mountain site are relatively few. The six families identified were: *Agriophyllum* spp., *Corispermum* spp., *Kochia* spp., and *Salsola* spp. of the Chenopodiaceae, *Artemisia* spp. of Compositae, *Poa* spp. and *Sclerochloa* spp. of Poaceae, *Allium* spp. of Liliaceae, *Viola* spp. of Violaceae, and *Lagopsis* spp. of Lamiaceae.

Only two carbonized seeds were unearthed in CL1: *Lagopsis supina* of the Lamiaceae. The species of carbonized plant seeds unearthed in CL2 and CL3 were similar. The ubiquity and proportion of plant seeds in CL2 and CL3 were counted, respectively. Figures 5, 6 indicate that the proportion and ubiquity of *Agriophyllum squarrosum* were the highest, followed by *Artemisia sieversiana*, and no significant difference found between CL2 and CL3 in the Pigeon Mountain site. *Agriophyllum squarrosum* showed no signs of domestication. The size of *Artemisia sieversiana* unearthed was only about half compared to that of living *Artemisia sieversiana*. To estimate the importance of *Agriophyllum squarrosum* and *Artemisia sieversiana*, the calculation included the ubiquity of the taxa using the available botanical remains as a measure of

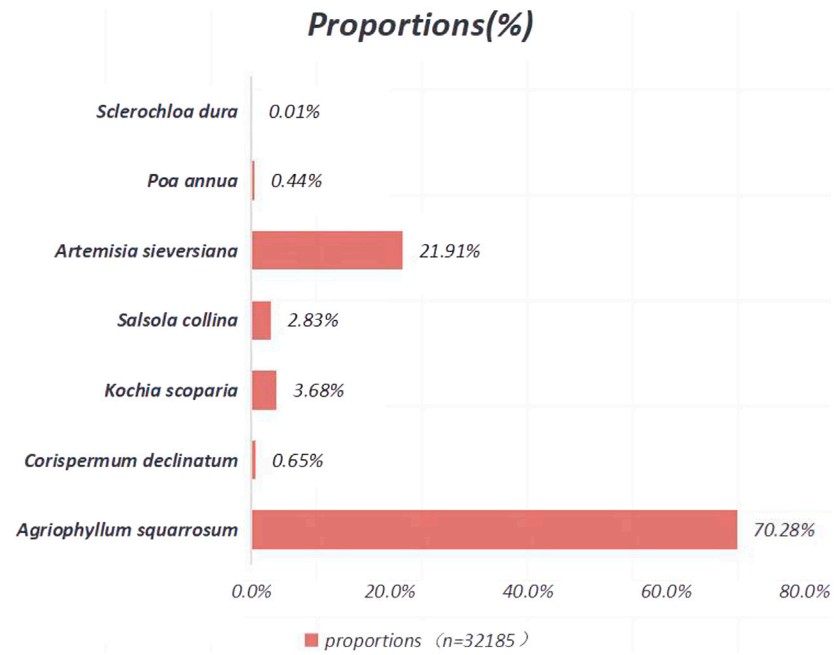


FIGURE 5
Proportions of species within the Pigeon Mountain site, CL3.

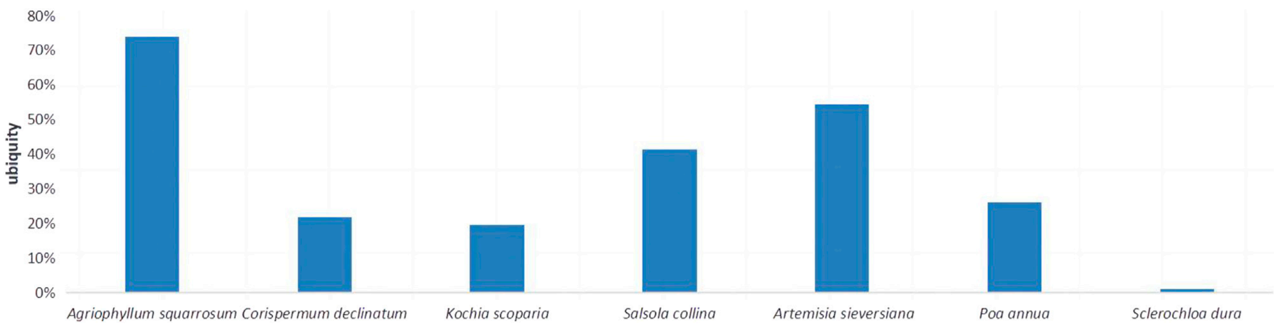


FIGURE 6
Ubiquity of species within the Pigeon Mountain site, CL3.

aggregation. This showed the high frequencies of the seeds at 70.28% and 21.91%, respectively.

Discussion

Paleo-environment and plant utilization in Mesolithic Northwest China

The proportion of *Tamarix* spp. in the Pigeon Mountain site is very high, which is the most widely distributed regional vegetation. The plants of Tamariaceae are all xerophytes, indicating that the climate is arid. The ubiquity of *Agriophyllum squarrosum* is also very high. *Agriophyllum squarrosum* is an annual summer and autumn plant that rarely develops in drought years. The appearance of the large number of *Agriophyllum squarrosum* indicates significant precipitation in summer. In addition, *Corispermum declinatum*, *Kochia scoparia*, and *Salsola collina* are also annual plants that develop in summer and autumn. According to the climatic characteristics of this study area, the rainfall season is conceived in summer. In the terrestrial ecosystem, the microenvironment plays a fundamental role in plant species' growth, germination, mortality, and reproduction (Cao et al., 2009). This role is essential because of the direct and indirect influence on essential processes such as nutrient cycles, evapotranspiration, and photosynthesis (Figures 7A–C). The changes in the vegetation composition and structure due to human activities and natural disturbances alter local conditions (Gehlhausen).

As *Corispermum declinatum*, *Kochia scoparia*, and *Agriophyllum squarrosum* show changes based on the

FIGURE 7
SEM microphotographs of *Tamarix*. **(A)** TS; **(B)** RLS; and **(C)** TLS.

environment, it demonstrates how the interaction of biotic and abiotic factors influences the microenvironment. This means that a change in the microenvironment influences the ecosystem and structural processes (Behera). Among the changes observed at the Pigeon Mountain site, the changes in the ecosystem are increased air and soil pressure, solar radiation levels, and decreased relative humidity, soil moisture, and vapor pressure. The Pigeon Mountain site has provided an exciting system for analyzing the relationship between variations in plant composition and structure and the microenvironment. This shows that the ecosystem has specific environmental conditions for plants to grow despite the climatic conditions. The topography of the Pigeon Mountain Site shows that the most common species found are mainly flowery plants such as *Artemisia sieversiana*. The number of plant species in the region shows the variation in environmental conditions based on the topography, moisture, and degree of disturbances.

Plants are essential to our well-being and they are included in people's food, religions, cultures, and medicines. The vital component of plants results in plant species' coevolution and domestication (Guo and Li, 2014). The archaeological practices to identify ancient practices ensure that indigenous plants do not become extinct because of environmental changes and human adaptation to modern plantation. Ancient people of the Pigeon Mountain site strengthened their utilization of herbal plants for a long time. The use of plant resources by ancient ancestors mainly includes two aspects: wooden tools and edible resources (Guo and Li, 2014). Wooden tools are commonly used for building materials, firewood, and tool-making. At the same time, edible resources focused on collecting seeds, fruits, roots, stems, and leaves of various plants. Almost all the remains of carbonized seeds unearthed in and around the archaeological site remain in the Pigeon Mountain site appearance (Cao et al., 2009). The ancient ancestors of the Pigeon Mountain site used fire frequently, and firewood resources, such as *Tamarix* spp., *Myricaria* spp., *Tetraena mongolia*, *Zygophyllum* spp., and *Caragana korshinskii*, were abundantly found. Therefore, the occupants of the Pigeon Mountain site did not have to collect the stems of herbs for fuel.

The community-staggered zone is also named the ecological or ecological transition zone. The environmental conditions of the community-staggered zone are relatively complex, which can provide growth conditions for plants of different ecological types, even species unique to the staggered region (Cao et al., 2009). The QG10 is located in a transitional area from grassland to the desert. It is also a community-interlaced area, providing conditions for human development and selecting a wider variety of food resources.

Diet structure and subsistence patterns of ancestors at the Pigeon Mountain site

Related theories, such as the optimal foraging theory (Smith, 1983; Pyke, 1984; Yi et al., 2013), Niche construction theory (Odling-Smee, 1988; Smith, 2011), and adaptation cycle theory, all explain the adjustment of the survival strategies of ancient humans to a specific period, such as the transition from a hunter–gatherer economy to an agricultural economy. According to the cost and return rate in development and utilization, natural resources can be divided into different grades. Ancient humans always preferred natural resources at higher rates of return. However, when specific high-return resources were scarce or difficult to obtain due to climate change or over-exploitation of specific resources, ancient humans had to include natural resources with relatively low returns to expand food sources (Piperno and Pearsall, 1998). Among all kinds of natural resources, the return rate of plant resources is usually lower than animal resources (Piperno, 2011). Therefore, ancient humans likely used animal resources first and then various plant resources.

Even the animal bones unearthed at QG10 are the highest (Zhang et al., 2019). The number of plant remains obtained by flotation and residue analysis is exceptionally abundant, which may indicate adaptions made by the ancestors of the QG10 in exploiting natural resources. Herb-seed plants, such as *Agriophyllum squarrosum* and *Artemisia sieversiana*, are primarily annual plants with solid recovery ability, which can meet the needs of the continuous utilization of ancient humans. In addition, grass-seed plants are productive and can be stored; this can also help the Pigeon Mountain site populations get through the harsh condition and food-scarce winter. In summary, grass-seed plants have been strengthened in the selection and utilization at the Pigeon Mountain site, indicating the ancient humans' adaption strategy to the living environment.

The current research and various relic phenomena and relics unearthed can provide valuable information about ancient ancestors' survival and adaptation ability in arid areas. First, grinding tools such as stone grinding discs and grinding rods were unearthed at Locality 10 (Guo et al., 2017). The residue analysis identified many starches of grasses, tubers, and other plant types on the surface (Guan et al., 2020). The existence of the ancestors' grinding behavior indicates that plant processing and utilization frequency were improved and strongly dependent on plant resources. Second, the suspected column–hole remains found in Layer4 are characterized by uniform horizontal distribution, strip-like, similar inner diameters, and similar internal contents. They contain much large amounts of *Tamarindaceae* charcoal, indicating the possibility of early attempts to build huts at the Pigeon Mountain site, though it still needs further discussion. The rich relic phenomenon and the continuous distribution of the culture layer indicate that ancient humans lived in this area for a long time. In addition, plenty of fire remains were found on the site, including many fire ponds with clear structures, indicating the ancestors of the site had behaviors such as heating and even cooking animal and plant resources and adapted to changes in the environment.

In the QG10, *Agriophyllum squarrosum* dominated the unearthed plants in number and ubiquity. Thus, the seeds of *Agriophyllum squarrosum* seem to be one of the most important food sources for the ancient people at the Pigeon Mountain site. However, according to textual research studies, there is no cultivation tradition of *Agriophyllum squarrosum* in China or other countries. In our observation, seeds unearthed in the Pigeon Mountain site did not show domestication characteristics, so further research is needed.

The dried seeds of *Artemisia sieversiana* can be ground into *Artemisia* powder, which is sticky when exposed to water. When kneaded with flour and water, the *Artemisia* powder can refine the flour and be kneaded into the soft and flexible dough to make *Artemisia* seed noodles. The seeds of *Artemisia sieversiana* could improve the digestion in humans. Therefore, we speculate that the ancestors of the Pigeon Mountain site used the seeds of *Artemisia sieversiana* to bind the powder made by other seeds (or fruits) and then ate them. Among the plant food resources unearthed from the Pigeon Mountain site, the resources that can be ground into powder include *Agriophyllum squarrosum* and *Elaeagnus angustifolia*. In addition, the tender leaves of *Artemisia sieversiana* are edible, and *Artemisia sieversiana* seeds were used as a source of oil by ancient ancestors.

Conclusion

Some scholars believe that in the Mesolithic in North China, hunter–gatherers experienced a shift from a "forager" to a "gatherer" strategy, which means an intensification of sedentism began to take advantage of seasonally growing wild animals. Plant resources unearthed from QG10 first provided good context evidence for human adaptation in the arid paleoenvironment. Plentiful seeds and remains illustrated that the ancient people in QG10 has explored a broader food spectrum, especially plant resources.

The taxa represented in the macro-botanical evidence of QG10 indicate in terms of land use and utilization of wild plant resources. The macro-botanical species, i.e., *Agriophyllum squarrosum*, as the most prosperous species, could be the most crucial food resource of ancient people in this region, even with no evidence of domestication. Abundance of *Artemisia sieversiana* floating from the sediments with a large number of grindstones of QG10 displays the possibility of reprocessing behavior for the seeds.

The existence of the Mesolithic is still under debate in China. In eastern China, some clues of the earliest pottery and agriculture were seen as the landmark of the transition period from Paleolithic to Neolithic. Nonetheless, the scenario was unclear in Western China, particularly in the northwest arid region. Archaeobotany evidence from QG10 provided reliable and AMS-dated *in situ* evidence to give rise to a possible answer to the Mesolithic in this region. Meanwhile, this new finding shed light on the possibility that the subsistence patterns of hunter–gatherers in arid environments underwent a severe shift during the Mesolithic, marked by the extensive use of wild plant resources.

Data availability statement

The raw data supporting the conclusion of this article will be made available by the authors, without undue reservation.

Author contributions

ZZ, FP, and XZ designed the study. XZ, FP, SW, JG, HW, XG, and ZZ conducted the study. XZ and FP 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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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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