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New insights into the subsistence economy of the Late Bronze Age (1100–400 cal BC) communities in the southeastern Baltic

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Abstract

This paper presents the findings of a research project aimed at reconstructing the subsistence economy of the Late Bronze Age communities in eastern Lithuania. We focused on examining archaeobotanical and zooarchaeological assemblages from three hillforts alongside $\delta^{13}C$ and $\delta^{15}N$ stable isotope analysis of plant and animal remains. Our results suggest that local populations primarily relied on growing domestic plants and animals for their subsistence. By the Late Bronze Age, they had already adopted a diverse package of cultivated plants, with barley and millet being the main crops. Also, inhabitants relied on pig and goat/sheep as a primary source for their protein intake. Finally, $\delta^{13}C$ and $\delta^{15}N$ measurements suggest that farmers engaged in intensive agriculture with semi-permanent field systems and moderate application of manure.

Introduction

Understanding subsistence strategies of past human populations plays a key role in analysing the social, economic and technological development of prehistoric communities. It is therefore not surprising that in recent years research focused on diet, agricultural development and impact on the environment of the Neolithic and Bronze Age inhabitants of northern Europe has been gathering momentum. Amongst other studies, these include inquiries into adoption and spread of agriculture and animal

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husbandry (Sørensen 2014; Lahtinen, Rowley-Conwy 2013; Piličiauskas et al. 2017b; Vanhanen et al. 2019; Gron 2020), changes in diet (Piličiauskas et al. 2017a, 2018; Robson et al. 2019) and the environment (Nielsen et al. 2019; Gron et al. 2021; Tserendorj et al. 2021).

The southeastern Baltic region, located at the northeastern fringes of the Neolithic agricultural frontier (Zvelebil 2001), requires particular attention. Despite some recent advancements (e.g. Piličiauskas et al. 2017b; Simčenka et al. 2022), the region is still underexplored, which hinders our ability to examine the agricultural development in northern Europe on a broader scale. The apparent lack of archaeobotanical and zooarchaeological evidence resulted in the perception of subsistence strategies of local Late Bronze Age communities as relatively simplistic. It has been suggested that these populations primarily relied on animal husbandry, hunting and fishing, while only engaging in extensive forms of farming which were of secondary economic importance (Girininkas 2013; Girininkas and Daugnora 2015).

So far, the absence of direct evidence has left little room for other hypotheses. However, a few Late Bronze Age settlements excavated over the last decade provided datasets (e.g. Pollmann 2014; Minkevičius et al. 2020) which seem to challenge this perspective. These suggest that local communities already cultivated a diverse package of crops and engaged in intensive forms of farming. Yet this was insufficient to construct a more complete picture of Late Bronze Age agriculture in the region, let alone comprehend wider transformations within society. Failure to understand the development of subsistence economy hinders our ability to explore its role in and impact on the changing social interactions during the 1st millennium BC. This study presents new representative archaeobotanical, zooarchaeological and stable carbon and nitrogen isotope data from recently excavated hillforts with the aim of exploring the agricultural development of the region in greater detail.

1. Site description

The zooarchaeological and archaeobotanical material for this study originates from three hillforts in eastern Lithuania (Fig. 1). Each of the sites contain cultural layers dated to the Late Bronze Age (ca. 1100–400 BC) and finds attributed to the Striated Ware culture. Two of the sites, Garniai I and Mineikiškės, have a single occupation horizon and are located at the epicentre of the Striated Ware culture. The other, Gediminas Hill, is a multi-phase site dating from the Bronze Age to the early modern period.

Garniai I is a settlement located in northeastern Lithuania, on the left bank of the River Kriaukė. An area of 72 m² was excavated in 2016–2017 and the site was dated to 786–541 cal BC (Podėnas 2020). During 2021 excavations, an area of 35 m² was uncovered. Most of the archaeological layer had already been destroyed by modern agricultural activity. However, a surviving fragment of 10.36 m² in size was investigated (Fig. 1). Four archaeological features were discovered, which included three postholes and a potsherd concentration (Gaižauskas 2022). Archaeological finds included 134 fragments of the Late Bronze Age pottery, three stone tools, a needle, a pin, an awl, three unidentified bone tools, two decorative bronze plates, and a few fragments of bronze casting waste. The zooarchaeological and archaeobotanical material has survived relatively well and was collected for further analysis.

Mineikiškės is another Late Bronze Age site in northern Lithuania. It is situated on the left bank of the River Nikajus. The settlement was previously investigated in 2017. An area of 10 m² was uncovered and the site was dated to 790–547 cal BC (Podėnas 2020). In 2020, an additional area of 30 m² was excavated. A well-preserved archaeological layer reaching up to 62 cm in thickness, two potsherd concentrations, a fragment of a stone pavement and 132 negative features were discovered (Minkevičius et al. 2021). The features included one domestic pit, one unidentified feature and 130 postholes. Of these, 15 were attributed to buildings, with the rest belonging to two types of defensive structure — an irregular enclosure and a narrow pole palisade (Fig. 1) (Podėnas et al. 2022). This implies that the excavated trench lies within the defensive area of the settlement. Ca. 4,000 fragments of Late Bronze Age pottery were discovered, alongside 53 artefacts: bone pins, scrapers, awls, polished stone axes, chisels, tools for grinding and polishing, and a few fragments of a clay crucible of a Akozino-Mälar-type axe casting mould (Minkevičius et al. 2021). The abundance and condition of the discovered zooarchaeological material indicated a favourable preservation environment for plant and animal remains collected for this study.

Gediminas Hill is a multi-horizon hillfort in eastern Lithuania. It sits on the left bank of the River Vilnia and has been investigated since the 1930s. The chronology of the site spans a period from the Late Bronze Age to the 17th century. In 2019, excavations were conducted at various locations around the hillfort, which resulted in a total area of ca. 123 m² being investigated (Kontrimas 2020). In one of the test pits located on the N side of the hill, a 2 x 2 m fragment of an undisturbed Late Bronze Age layer was discovered. The layer contained 38 fragments of Late Bronze Age pottery, 16 clay daub fragments and one flint flake. Only a few small animal bone fragments were discovered. However, the layer produced a rich archaeobotanical assemblage which was later sampled for isotopic analysis.

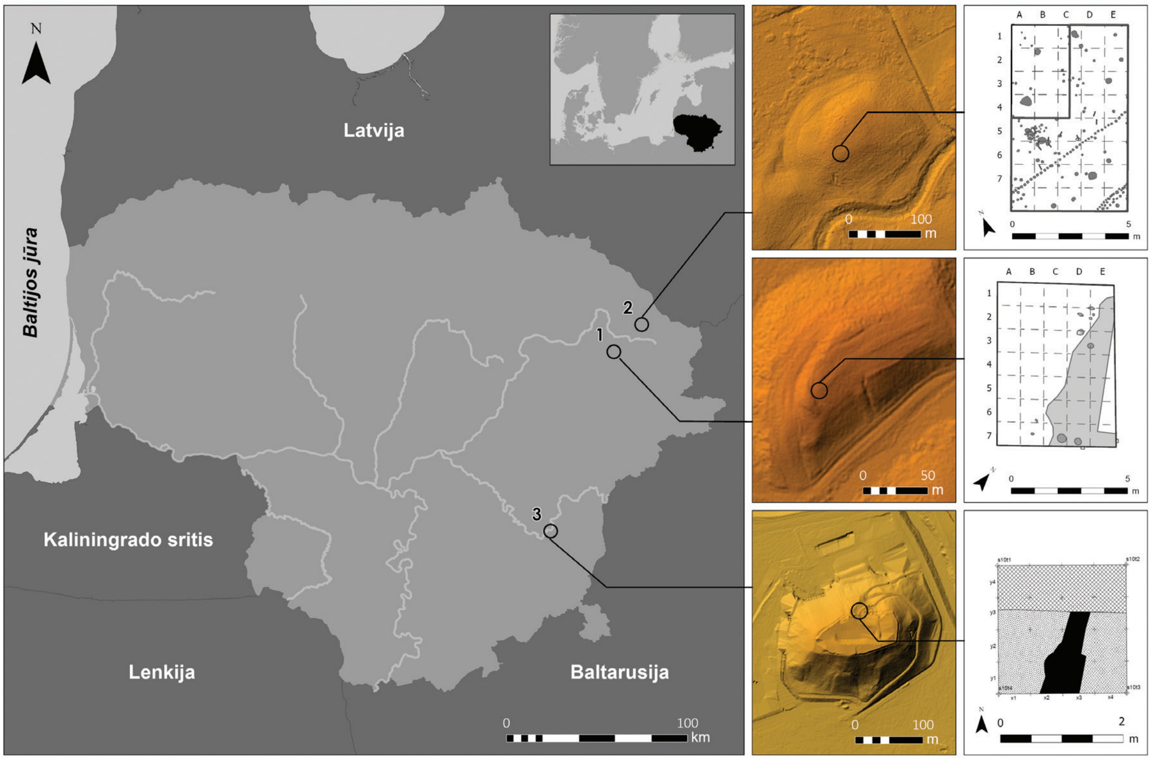

Figure 1. Analysed sites: 1 – Garniai I; 2 – Mineikiškės; 3 – Gediminas. (by Minkevičius).

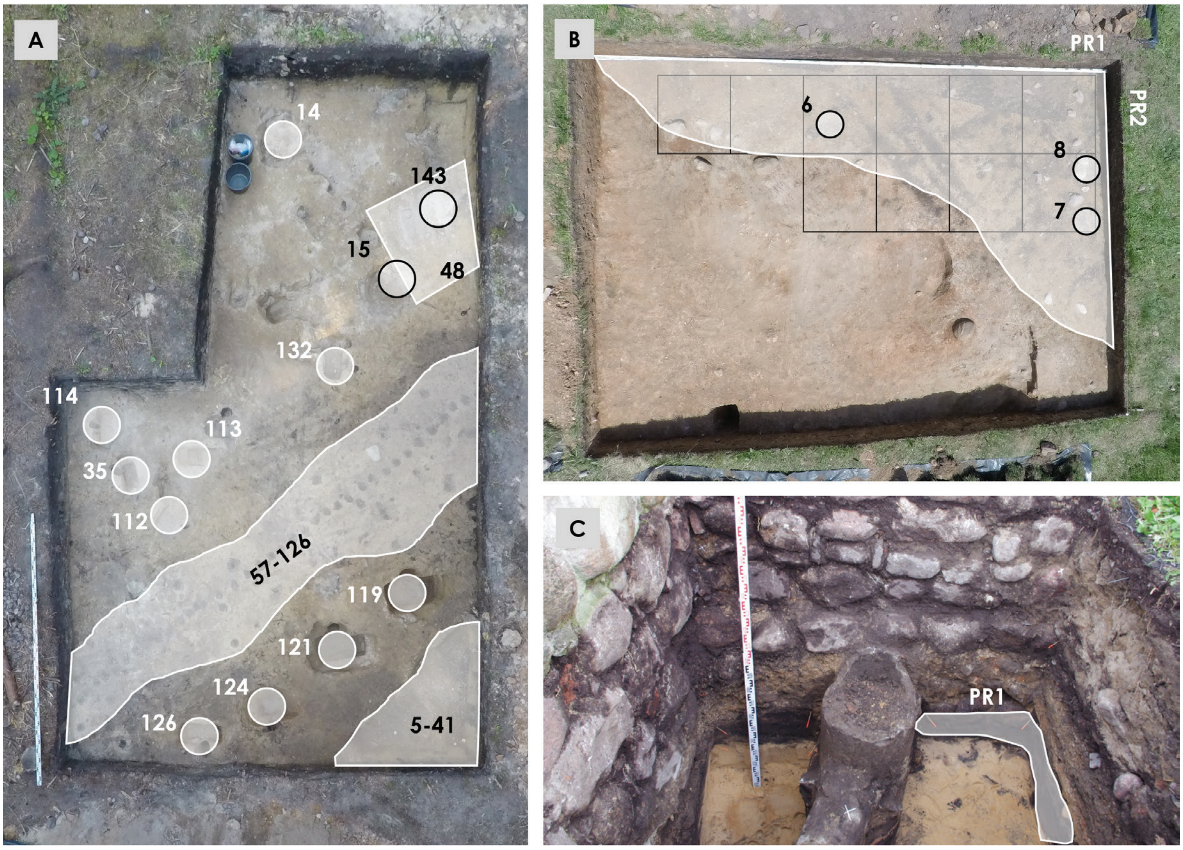

Figure 2. Sampled contexts: A – Mineikiškės; B – Garniai I; C – Gediminas Hill. Numbering of the archaeological features follows the numbering in the excavation. (by Podėnas and Kontrimas).

2. Material and methods

2.1. Archaeobotanical analysis

During 2020–2021 excavations at Mineikiškės and Garniai I settlements respectively, 128 and 21 soil samples ranging from 0.1 to 20 l in volume (250.55 l in total) were collected (Table 1). Samples were taken from undisturbed cultural layer sections in a grid pattern, trench profile columns, and archaeological features, such as postholes and pits (Fig. 2) following a probabilistic sampling strategy as described by d'Alpoim Guedes and Spengler (2014). Samples were processed in the field using manual bucket flotation. The floating fraction was collected using steel sieves with a mesh size of 300 μm. Heavy fraction and small finds were retrieved using a glass-fibre net with 1.4 mm aperture. Dried material was sorted and examined under a binocular microscope with x10 to x120 magnification. Plant macrofossils were identified using botanical atlases and identification keys (Grigas 1986; Jacquat 1988; Latałowa 1999; Cappers et al. 2012), and comparative collections of fossil and modern plants which are housed at the Laboratory of Quaternary Research, Nature Research Centre (Vilnius). Archaeobotanical taxonomy is presented following Zohary et al. (2012).

Table 1. Information on the analysed samples and (*) data taken from the excavation report by D. Kontrimas (2020).

	Site		Garniai I	Mineikiškės	Vilnius I
	No. of samples		21	128	1*
Context type					
Posthole			4	122	-
Domestic pit			-	2	-
Cultural layer			10	-	-
Profile section			7	-	1
Unidentified feature			-	4	-
Total volume sampled (l)			116.20	134.35	23

2.2. Zooarchaeological analysis

The research was carried out in the Zooarchaeology Laboratory of Vilnius University using a comparative collection of mammal and fish bones. At the Garniai I site, 2,432 animal bones (2,389 specimens in 2016–2017 and 43 fragments in 2020) were collected. Meanwhile, at Mineikiškės, 7,848 pieces of animal skeletal remains were found and analysed (2,711 pieces in 2017 and 5,237 specimens in 2020). The minimum number of individuals (MNI) was estimated according to White (1953) and the epiphyseal fusion and teeth eruption time was determined according to Silver (1969). Sheep and goat bones were identified according to Boessneck et al. (1964), Schramm (1987), and Prummel and Frisch (1986). Animal remains collected during the excavations of 2020 were identified by Giedrė Piličiauskienė and zooarchaeological material from previous excavations of 2016–2017 was identified by Viktorija Micelicaitė. Analysed animal remains are stored in the Zooarchaeological Repository of Vilnius University, Faculty of History.

2.3. AMS ^{14}C dating

Twelve charred plant macrofossils and two samples of animal bone tissue were submitted for radiocarbon dating (Table 2). AMS radiocarbon (^{14}C) dating was performed at the Mass Spectrometry Laboratory Centre for Physical Sciences and Technology, Vilnius. The standard acid-base-acid (ABA) pre-treatment was used for charred botanical and faunal remains. Collagen extraction was performed using the ABA method followed by gelatinisation (Szidat et al. 2017). Radiocarbon dates were calibrated in OxCal v4.4. software using IntCal20 atmospheric curve (Bronk Ramsey 2009; Reimer et al. 2020). Calibrated dates are presented at 95.4% probability.

Table 2. AMS ^{14}C measurements from the sites analysed in this study. (*)
First published in Podėnas et al. (2022).

No.	Site	Bot. sample ID	Lab. code	^{14}C date (BP) ± error	cal BC (95.4%)
	Garniai I				
1	*Cerealia* (grain)	11	FTMC-GA07-1	2528 ± 29	793-545
2	*Cerealia* (grain)	12	FTMC-GA07-2	2579 ± 34	811-568
	Mineikiškės				
3	Wood charcoal	2	FTMC-PH58-4	2758 ± 28	983-827
4	cf. *Hordeum vulgare* (grain)	4	FTMC-GA07-3	2557 ± 28	803-566
5	*Cerealia* (grain)	85	FTMC-GA07-4*	2579 ± 30	811-573
6	Wood charcoal	20	FTMC-GA07-5*	2489 ± 28	775-491

Table 2. Continuation

No.	Site	Bot. sample ID	Lab. code	^{14}C date (BP) ± error	cal BC (95.4%)
7	Wood charcoal	92	FTMC-PH58-5	2364 ± 28	538-388
8	Wood charcoal	27	FTMC-GA07-6	2435 ± 30	751-406
9	Wood charcoal	111	FTMC-GA07-7	2459 ± 28	756-416
10	Wood charcoal	114	FTMC-PH58-6	2477 ± 29	770-426
11	*Cerealia* (grain)	127	FTMC-PH58-7	2603 ± 31	822-675
12	*Hordeum vulgare* (grain)	38	FTMC-GA07-8	2510 ± 29	783-541
13	Horse (metacarpus)	-	FTMC-38-15	2448 ± 27	752-412
14	Cattle (metacarpus)	-	FTMC-PH58-1	2537 ± 29	796-547
	Vilnius I				
15	*Hordeum vulgare* (grain)	5	FTMC-PH58-8	2494 ± 28	776-517
16	*Hordeum vulgare* (grain)	5	FTMC-CK63-6	2709 ± 35	918-806

2.4. Stable isotope analysis of archaeobotanical and zooarchaeological remains

Three Late Bronze Age archaeobotanical assemblages from Garniai I, Mineikiškės and Gediminas Hill hillforts were sampled for the analysis. Up to ten charred grains belonging to each of the staple cereal taxon were selected from each site. These included barley (*Hordeum vulgare*), emmer (*Triticum dicoccon*), spelt (*Tr. spelta*), and broomcorn millet (*Panicum miliaceum*). Ideally, ca. ten grains would be preferred in each case (Nitsch et al. 2015). However, in archaeological contexts this is often not possible due to poor preservation of the material. In this case, the actual number of samples ranges from 0 to 10 (Table 3). Each specimen was chemically pre-treated using the standard ABA treatment. The samples were manually homogenised using a mortar and pestle and weighed into tin capsules. Measurements were undertaken at the Centre for Physical Sciences and Technology, Vilnius using a Thermo Flash EA 1112 elemental analyser coupled to a Thermo Finnigan Delta+ Advantage mass spectrometer. Isotope data were normalised to VPDB (Vienna Pee Dee Belemnite) scale for C and AIR (Ambient Inhalable Reservoir) for N using IAEA standards. The δ^{13}C and δ^{15}N values of the carbonised crop remains were corrected for charring offset by subtracting 0.11‰ and 0.31‰ respectively (Nitsch et al. 2015).

δ^{13}C and δ^{15}N stable isotope analysis was undertaken at the Centre for Physical Sciences and Technology, Vilnius. Bone collagen extraction was performed according to the acid-alkali-acid (AAA) procedure followed by gelatinisation (Szidat et al. 2017). Samples were treated with 0.5M hydrochloric acid, 0.1M sodium hydroxide and 0.5M hydrochloric acid. Bone collagen gelatinisation was performed in pH 3 solution at 70°C for 20 hours. Gelatin solution was filtered using a cleaned Ezee-filter and freeze-dried. For ^{14}C δ^{13}C and δ^{15}N measurements, the same collagen aliquot was used. Stable carbon and nitrogen isotope ratio values in the bone collagen were measured using an elemental analyser (Thermo FlashEA 1112) connected to an Isotope Ratio Mass Spectrometer (Thermo Finnigan Delta Plus Advantage). The analytical precision for δ^{13}C and δ^{15}N was ± 0.1‰ and ± 0.15‰ respectively. Stable isotope data is reported as δ values in permille (‰) relative to international standards: VPDB for δ^{13}C and AIR for δ^{15}N. To ensure the collagen was of sufficient quality, four collagen quality parameters measured in bone samples were used as indicators of collagen integrity (De Niro 1985; Ambrose 1990; Van Klinken 1999).

3. Results and Discussion

3.1. Chronology of plant and animal remains

Two charred cereal grain fragments were dated from the Garniai I settlement (Table 2). Calibrated dates fall in the range of 811–545 cal BC (2σ). The dates are within the Hallstatt radiocarbon calibration plateau (ca. 800–400 cal BC) which hinders the possibility to narrow down the chronology on the basis of radiocarbon dates. Nonetheless, the dates confirm the previously established chronology of the settlement (8th–6th centuries) which was based on artefact typology and stratigraphy of the site (Gaižauskas 2022).

Ten samples were dated from the Mineikiškės assemblage. These included five wood charcoal fragments, three charred cereal grains and two animal bone fragments. Calibrated dates fall within the range of 983–406 cal BC (2σ). Determination of the site's chronology is further complicated by the layout of the defensive structures. Their spatial organisation, coupled with the radiocarbon dates from the respective posthole fills, hint at two phases of settlement fortification, which could indicate the prolonged use of the site (Podėnas et al. 2022). Yet it has previously been suggested that the settlement belongs to the 8th–6th centuries BC (Podėnas 2018), which is confirmed by the new series of ^{14}C dates.

Table 3. Isotopic results of the archaeological plant remains analysed in the study. Corrected $\delta^{15}N$ (-0.31 ‰) and $\delta^{13}C$ (-0.11 ‰) vales have been used to offset the charring effect.

Sample	**Sample ID**	**%N**	**%C**	**$\delta^{15}N$**	**$\delta^{13}C$**	**C:N atomic**	**$\delta^{13}C_{air}$**	**$\Delta^{13}C$**
Garniai I								
Hordeum nudum (grain)	GRN1-21-1	1.83	32.04	4.48	-25.54	20.42	-6.5	19.54
Hordeum vulgare (grain)	GRN1-21-2	2.26	41.08	6.98	-25.50	21.20	-6.5	19.50
Hordeum vulgare (grain)	GRN1-21-3A	1.87	50.14	4.76	-25.32	31.20	-6.5	19.31
Hordeum vulgare (grain)	GRN1-21-3B	1.74	38.66	6.31	-24.36	25.85	-6.5	18.31
Hordeum vulgare (grain)	GRN1-21-5A	1.23	30.24	4.06	-25.02	28.74	-6.5	19.00
Hordeum vulgare (grain)	GRN1-21-5B	1.46	33.51	4.63	-25.66	26.74	-6.5	19.67
Hordeum vulgare (grain)	GRN1-21-6A	1.27	31.68	4.80	-24.34	29.08	-6.5	18.29
Hordeum vulgare (grain)	GRN1-21-6B	1.87	46.54	5.59	-24.13	29.09	-6.5	18.06
Hordeum vulgare (grain)	GRN1-21-8	1.70	41.14	4.41	-25.25	28.20	-6.5	19.23
H. vulgare. var. *vulgare* (grain)	GRN1-21-9	1.80	36.71	5.17	-24.56	23.76	-6.5	18.52
Panicum miliaceum (grain)	GRN1-21-15	2.33	41.39	6.45	-11.26	20.73	-6.5	4.81
Panicum miliaceum (grain)	GRN1-21-17	2.42	43.56	5.94	-10.75	20.99	-6.5	4.30
Panicum miliaceum (grain)	GRN1-21-19	2.47	45.96	6.11	-11.04	21.72	-6.5	4.59
Panicum miliaceum (grain)	GRN1-21-20	1.27	20.77	6.36	-10.46	19.06	-6.5	4.01
Panicum miliaceum (grain)	GRN1-21-21	1.61	27.03	6.42	-11.69	19.54	-6.5	5.25
Panicum miliaceum (grain)	GRN1-21-22	2.12	31.35	4.34	-11.41	17.25	-6.5	4.97
Panicum miliaceum (grain)	GRN1-21-23	1.78	31.39	6.40	-10.80	20.57	-6.5	4.35
Panicum miliaceum (grain)	GRN1-21-24	1.30	18.69	6.30	-11.15	16.84	-6.5	4.70
Mineikiškės								
Panicum miliaceum (grain)	MNK20-5	2.64	40.39	6.15	-10.69	17.87	-6.5	4.23
Panicum miliaceum (grain)	MNK20-6	2.33	32.22	8.86	-11.92	16.16	-6.5	5.49
Panicum miliaceum (grain)	MNK20-7	2.33	49.86	6.67	-10.44	24.95	-6.5	3.98
Hordeum vulgare (grain)	MNK20-41	3.50	35.84	6.72	-23.66	11.93	-6.5	17.57
Vilnius I								
Hordeum vulgare (grain)	VPL-19-5-1	2.70	49.06	3.34	-27.95	21.23	-6.5	22.06
Hordeum vulgare (grain)	VPL-19-5-2	1.82	51.82	4.12	-26.16	33.14	-6.5	20.19
Hordeum vulgare (grain)	VPL-19-5-3	1.87	42.77	4.82	-26.49	26.64	-6.5	20.53
Hordeum vulgare (grain)	VPL-19-5-4	2.09	46.65	5.38	-26.34	26.09	-6.5	20.38
Hordeum vulgare (grain)	VPL-19-5-5	0.91	44.50	3.34	-23.91	57.02	-6.5	17.84
Hordeum vulgare (grain)	VPL-19-5-6	2.20	47.72	4.94	-26.41	25.33	-6.5	20.45
Hordeum vulgare (grain)	VPL-19-5-7	1.90	35.45	6.60	-26.26	21.80	-6.5	20.29
Hordeum vulgare (grain)	VPL-19-5-8	1.85	52.72	2.81	-24.84	33.33	-6.5	18.81
Hordeum vulgare (grain)	VPL-19-5-9	1.89	46.31	4.54	-25.02	28.60	-6.5	19.00
Hordeum vulgare (grain)	VPL-19-5-10	1.75	52.15	4.25	-26.89	34.72	-6.5	20.95
Triticum dicoccon (grain)	VPL-19-5-11	3.40	45.60	5.17	-23.37	15.63	-6.5	17.27
Triticum dicoccon (grain)	VPL-19-5-12	2.90	48.52	4.60	-24.80	19.53	-6.5	18.77
Triticum dicoccon (grain)	VPL-19-5-13	2.51	48.23	4.77	-24.04	22.45	-6.5	17.97
Triticum dicoccon (grain)	VPL-19-5-14	2.66	47.74	4.81	-26.20	20.95	-6.5	20.23
Triticum dicoccon (grain)	VPL-19-5-15	2.44	45.23	4.78	-24.65	21.64	-6.5	18.61

Table 3. Continuation

Sample	Sample ID	%N	%C	δ^{15}N	δ^{13}C	C:N atomic	$\delta^{13}C_{air}$	Δ^{13}C
Triticum dicoccon (grain)	VPL-19-5-16	2.49	45.16	4.07	-24.79	21.15	-6.5	18.75
Triticum dicoccon (grain)	VPL-19-5-17	2.41	47.21	3.53	-24.63	22.86	-6.5	18.59
Triticum dicoccon (grain)	VPL-19-5-18	2.94	50.44	4.95	-25.21	19.99	-6.5	19.20
Triticum dicoccon (grain)	VPL-19-5-19	3.20	49.77	4.45	-24.12	18.15	-6.5	18.05
Triticum dicoccon (grain)	VPL-19-5-20	2.71	46.77	4.31	-23.67	20.13	-6.5	17.58
Triticum spelta (grain)	VPL19-5-21	2.56	44.08	4.16	-24.59	20.06	-6.5	18.55
Triticum spelta (grain)	VPL19-5-22	2.71	54.23	4.61	-25.10	23.36	-6.5	19.07
Triticum spelta (grain)	VPL19-5-23	2.55	47.65	4.46	-24.13	21.76	-6.5	18.07
Triticum spelta (grain)	VPL19-5-24	2.45	54.37	5.48	-24.14	25.92	-6.5	18.07
Triticum spelta (grain)	VPL19-5-25	2.49	43.56	5.56	-23.30	20.42	-6.5	17.20
Panicum miliaceum (grain)	VPL19-5-26	2.56	47.96	5.92	-11.13	21.85	-6.5	4.68
Panicum miliaceum (grain)	VPL19-5-27	2.31	47.71	5.44	-10.83	24.12	-6.5	4.37
Panicum miliaceum (grain)	VPL19-5-28	3.47	45.68	5.31	-11.31	15.35	-6.5	4.87
Panicum miliaceum (grain)	VPL19-5-29	2.27	45.99	5.92	-10.68	23.63	-6.5	4.22
Panicum miliaceum (grain)	VPL19-5-31	3.44	50.57	6.27	-12.76	17.15	-6.5	6.34
Panicum miliaceum (grain)	VPL19-5-33	2.46	53.09	6.05	-10.51	25.14	-6.5	4.05
Panicum miliaceum (grain)	VPL19-5-34	2.87	40.92	6.59	-11.15	16.65	-6.5	4.70
Panicum miliaceum (grain)	VPL19-5-35	3.45	57.05	4.41	-10.61	19.29	-6.5	4.15

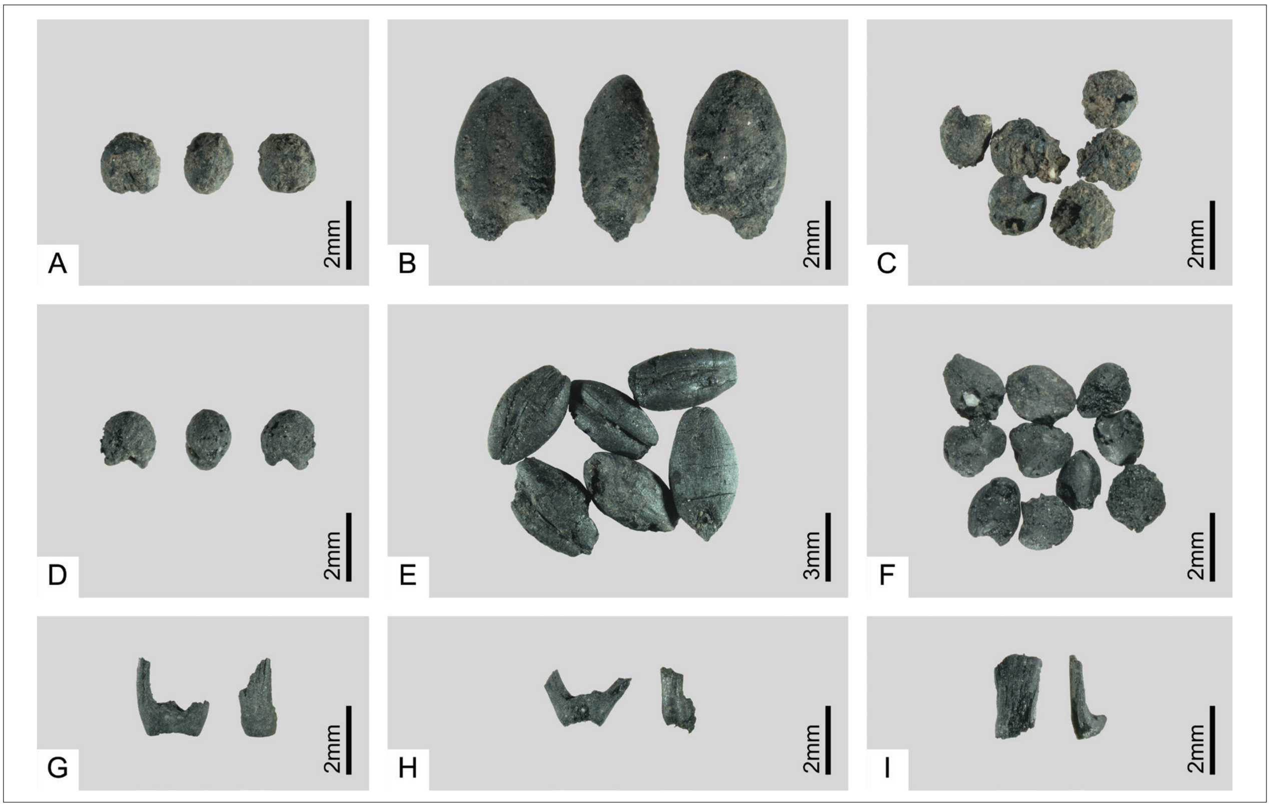

Figure 3. Charred plant macrofossils. Grains of (a, c) *Panicum miliaceum* and (b) *Hordeum vulgare* from Garniai I; (d) *Panicum miliaceum* grain from Mineikiškės; (e) *Hordeum vulgare*, (f) *Panicum miliaceum* grains and (g, h) *Triticum dicoccon* and (i) *Triticum spelta* glume bases from Gediminas. (by Minkevičius).

Two charred barley grains from Gediminas Hill were dated to 918–806 cal BC (2σ) and 776–517 cal BC (2σ). While there is no overlap between the dates, it is evident that both samples came from the same undisturbed context. Thus a relatively wide timeframe depicted by the radiocarbon dates could suggest that the settlement was occupied for an extended period during the Late Bronze Age and the resulting archaeobotanical assemblage likely accumulated over the prolonged timeframe.

3.2. Archaeobotanical evidence

Out of 21 soil samples from Garniai I, 13 contained charred plant macrofossils (Fig. 3). A total of 71 plant remains were identified (Table 4). Most of the finds came from postholes (features 6 and 7) and the surviving fragment of the Late Bronze Age layer (Fig. 2). The majority of these (92.96%, n=66) belong to several crop species. Among these, grains of *Panicum miliaceum* (broomcorn millet) (n=30) and *Hordeum vulgare* (barley) (n=14) were identified. Grains of two barley varieties — *H. vulgare* var. *vulgare* (hulled barley) and *H. vulgare* var. *nudum* (naked barley) — were discovered.

Table 4. Charred plant macrofossils from the hilltop settlements in eastern Lithuania. Abbreviations: c=caryopsis; e=endocarp; f=fruit; gb=glume base; n=needle; s=seed.

Taxon	**Site**	**Garniai I**	**Mineikiškės**	**Vilnius I**
Cultivated plants	**Type of remains**			
cf. *Avena* sp.	c	-	-	1
Cerealia	c	21	8	136
Hordeum vulgare var. *nudum*	c	1		
Hordeum vulgare var. *vulgare*	c	1		25
Hordeum vulgare	c	12	2	38
cf. *Hordeum vulgare*	c	1	1	-
Lens culinaris	s	-	-	1
cf. *Lens culinaris*	s	-	-	2
Panicum miliaceum	c	30	4	10
Pisum sativum	s	-	1	-
cf. *Pisum sativum*	s	-	1	1
Triticum cf. *dicoccon*	c	-	-	20
Triticum dicoccon	gb fr.	-	-	9
Triticum cf. *spelta*	c	-	-	5
Triticum spelta	gb fr.	-	-	3
Triticum sp. (hulled)	c	-	-	5
Wild plants				
cf. *Bromus* sp.	c	-	-	2
Carex pairae	f	-	1	-
Carex cf. *vulpina*	f	1	-	-
Carex sp.	f	-	2	-
Chenopodium album	s	-	3	6
Corylus avellana	s	-	-	1
Corylus avellana	e fr.	-	-	3
Fallopia convolvulus	f	1	6	1
Galium mollugo	s	-	1	-
Galium spurium	s	-	1	1
Persicaria lapathifolia	f	-	1	-
Picea sp.	n fr.	-	-	1
Polygonum aviculare	f	1	1	-
Rubus idaeus	f	-	-	9
Setaria italica	c	-	-	5
Setaria pumila	c	-	-	1
Silene cf. *dioica*	s	2	-	-
Vicia cf. *cracca*	s	-	-	1
Fabaceae	s fr.	-	5	-
cf. Lamiaceae	fr.	-	1	-
Indet.	s/f fr.	-	10	6

Only 16 of 128 samples from Mineikiškės contained carbonised plant remains. A total of 49 macrofossils were discovered. Among these, crops constituted a significant portion (34.69%, n=17). Grains of *Panicum miliaceum* (broomcorn millet) (n=4) and *Hordeum vulgare* (barley) (n=2), alongside a single seed of *Pisum sativum* (pea), were identified. This shows that the density of plant macrofossils in samples was relatively low. Most of the finds came from features 15, 48 and 143, which all likely belong to the same structure, possibly a dwelling (Fig. 2). This could help to explain the apparent scarcity of finds in other features. Since most of the postholes belong to fortifications, the low find counts are to be expected.

The low overall number of archaeobotanical finds is a trait shared by Garniai I and Mineikiškės. Find density only reaches 0.61 n/l and 0.36 n/l respectively. In the case of Garniai I, only three negative features were discovered, alongside a small fragment of surviving Late Bronze Age layer, which might account for the scarcity of plant macrofossils. Mineikiškės, on the other hand, presents a different case because here the cultural layer was very well preserved. However, most of the samples came from the postholes of the palisade and the irregular enclosure. This indicates that only the defensive zone of the settlement was sampled, while grain-rich activity areas, such as those related to food processing and storage, were likely located in other parts of the site. Also, judging from the stratigraphy and the spatial layout of the site, the defensive structures were likely constructed during the beginning phase of the settlement's life cycle, making it less likely that finds like food processing waste could end up in the posthole fills.

The composition of crops at Garniai I and Mineikiškės is similar to the Gediminas Hill assemblage (Table 4). Samples are dominated by cereals, primarily barley and millet, while the proportion of pulses is negligible. However, a notable difference is the abundance of wheats at Gediminas Hill. Chaff fragments of *Triticum dicocco*n (emmer) and *Tr. spelta* (spelt) are especially interesting. Such finds are usually a by-product of food processing and thus could be indicative of dwellings or waste areas. This conforms to the overall pattern observed in other Late Bronze Age sites in Lithuania, which present a relatively uniform picture of 1st millennium BC agriculture, with only minor differences. For example, assemblages from Luokesa I and Turlojiškė were dominated by broomcorn millet (48% and 100% of crops respectively) (Antanaitis-Jacobs et al. 2002; Pollman 2014), while samples from the Kukuliškiai assemblage mainly consisted of barley (66%), millet (14%) and glume wheats (16%) (Minkevičius et al. 2020). This choice of crops in this region is not surprising. Barley was likely the first cereal introduced into the region (Piličiauskas et al. 2021), which is possibly linked to its resilience and adaptability to the cold climate of temperate Europe (Weisskopf and Fuller 2014). Cultivation of millet in Bronze Age Lithuania also started shortly after its introduction into northern Europe (Piličiauskas et al. 2022). This plant is an attractive emergency crop which could aid in mitigating the risk of crop failure. Due to its short life cycle, millet could be sown in late spring or even early summer if winter crops failed or produced meagre yields (Cappers and Neef 2012), which would have made it an ideal choice for the Bronze Age farmers in the region. The existing data is insufficient to properly address the apparent lack of wheats at Garniai I and Mineikiškės. While it is possible that wheat species in northeastern Lithuania were cultivated to a lesser extent due to differences in the local environment, it is also likely that these species are simply underrepresented in the samples due to the limited scale of the excavations.

The patterns observed in the composition of archaeobotanical assemblages closely resemble the broader tendencies in northern Europe. Throughout the Bronze Age, barley was a staple crop in Scandinavia, Germany, Poland and Finland (Wasylikowa et al. 1991; Robinson 2003; Grabowski 2011; Rösch 2013; Vanhanen et al. 2019), and towards the second half of the period, hulled *Hordeum vulgare* var. *vulgare* became the main crop in most of northern Europe. Its adaptability to the harsh environments of temperate Europe and resilience to environmental conditions (Hjelmqvist 1992; Buxó i Capdevila et al. 1997) likely made barley an ideal choice for this region. Broomcorn millet appears to have been another favourable crop for such an environment. Recent research revealed that *P. miliaceum* spread swiftly across northern Europe shortly after its introduction into the continent ca. 1550 cal BC (Filipović et al. 2020). Therefore, it is likely that material from hillforts in Lithuania indicate processes parallel to agricultural developments in the rest of northern Europe during the course of the Bronze Age.

3.3. Zooarchaeological evidence

A total of 531 (21.8%) and 1965 (24.7%) fragments were identified among the zooarchaeological material from Garniai I and Mineikiškės respectively. The relatively low percentage of identified bones is related to their high degree of fragmentation. Despite good preservation, animal remains analysed were extremely fragmented in both sites (mean 1 to 1.7 g/fragment).

The bones were smashed, crushed into small pieces and then probably cooked in an attempt to extract the maximum possible nutritional value. The proportion of burned bones was 5.1% in Garniai I and 7.0% in Mineikiškės (Micelicaitė et al. 2023). Such a proportion is relatively small compared to other sites and periods. For example, in the Subneolithic Šventoji 43 settlement site, burnt bones accounted for 63% of the finds (Piličiauskas et al. 2019a). Such differences could suggest different food preparation and waste utilisation practices in different periods.

Mammal bones predominated and comprised 90.1%–99.9% of all faunal remains at both sites (Tables 5 and 6). However, the Mineikiškės zooarchaeological material was unusually rich in fish remains (287, 3.6% bones, 240 scales) and mussel shells (n=500, 6.2%). Molluscs were represented by two species of river mussels — *Unio crassus* and *Unio tumidus* (Micelicaitė et al. 2023). Mollusc shells were also found at the Garniai I site but these could not be recovered due to poor preservation. Consumption of mussels is unusual not only for the analysed Lithuanian Late Bronze Age sites but for the eastern Baltic region in general. Here, molluscs were not a common food source

Table 5. Taxonomic and anatomical distribution of animal remains from Mineikiškės hilltop site. NISP = number of identified specimens, MNI = minimum number of individuals. Data from this study and Micelicaitė et al. 2023.

Animal/bone	**Horncore**	**Skull**	**Mandible**	**Teeth**	**Vertebrae**	**Scapula**	**Humerus**	**Radius**	**Ulna**	**Carpal bones**	**Metacarpus**	**Pelvis**	**Femur**	**Tibia**	**Fibula**	**Patella**	**Tarsal bones**	**Metatarsus**	**Phalanges**	**Metapodias**	**NISP**	**NISP, %**	**MNI**	**MNI, %**
Catlle *Bos taurus*	1	18	9	46	10	1	7	6	12	2	7	1	17	10			3	5	6	4	**165**	**8,4**	**7**	**9,2**
Sheep *Ovis aries*		1	2	2			3				4						1		2	2	**17**	**0,9**	**22**	**28,9**
Goat *Capra hircus*																			4		**4**	**0,2**		
Sheep/goat *Ovis aries / Capra hircus*		54	23	112	102	8	26	49	7	20	15	2	86	55			8	35	39	11	**652**	**33,2**		
Pig *Sus scrofa domesticus*		122	29	227	56	23	47	14	12	26	10	7	50	32	29	2	25	6	132	41	**890**	**45,3**	**21**	**27,6**
Horse *Equus ferus ferus / E. f. caballus*		11	14	44	9		4	2	1	2	3	1	1	7			2	1	2		**104**	**5,3**	**8**	**10,5**
Elk *Alces alces*				1	1																**2**	**0,1**	**1**	**1,3**
Red deer *Cervus elaphus*								1			1		2								**4**	**0,2**	**1**	**1,3**
Roe deer *Capreolus capreolus*				2		1							2								**5**	**0,3**	**1**	**1,3**
Boar *Sus scrofa scrofa*		1		2											1						**4**	**0,2**	**1**	**1,3**
Boar / pig *Sus scrofa scrofa / S. s. domesticus*			3	6									1		1						**11**	**0,6**	**1**	**1,3**
Beaver *Castor fiber*				1	1																**2**	**0,1**	**1**	**1,3**
Mountain hare/European hare *Lepus timidus / L. europaeus*		1	1		4	1	7	7	4		2	1	3	16			2	1	1	3	**54**	**2,7**	**3**	**3,9**
Red fox *Vulpes vulpes*		1	6	4	3			1	2		1			1			4	2	2	2	**29**	**1,5**	**3**	**3,9**
Otter *Lutra lutra*		1															1		1		**3**	**0,2**	**1**	**1,3**
European marten *Martes martes*			2		1			1											1		**5**	**0,3**	**1**	**1,3**
Mustelidae								1				1		2							**4**	**0,2**	**1**	**1,3**
Red squirrel *Sciurius vulgaris*		1	1									1	1								**4**	**0,2**	**1**	**1,3**
Small rodents		4	2																		**6**	**0,3**	**2**	**2,6**
In total	**1**	**215**	**92**	**447**	**187**	**34**	**94**	**82**	**38**	**50**	**43**	**14**	**163**	**123**	**31**	**2**	**46**	**50**	**190**	**63**	**1965**		**76**	
In total, %	**0,1**	**10,9**	**4,7**	**22,7**	**9,5**	**1,7**	**4,8**	**4,2**	**1,9**	**2,5**	**2,2**	**0,7**	**8,3**	**6,3**	**1,6**	**0,1**	**2,3**	**2,5**	**9,7**	**3,2**		**100,0**		**100,0**

and are rarely found in prehistoric contexts. Rinnukalns in Latvia, the only site famous for an abundance of molluscs, contained the same mussel species (Bērziņš et al. 2014). It is therefore possible that consumption of molluscs at Mineikiškės and Garniai I is related to food shortages experienced by the communities under consideration (Luik et al. 2022).

Most of the mammal bones from Mineikiškės and Garniai I are the remains of domestic animals, 93.2% and 89.7% respectively. Pig bone fragments were the most abundant, accounting for 45.3% at Mineikiškės and 57.8% at Garniai I (Tables 5 and 6). Sheep/goats were the second most abundant group at both sites (34.2% and 24.3% respectively), while cattle constituted only 6%–8.6%.

Domestic animals were slaughtered at different ages: sheep/goats usually either at around the age of 8–10 months or just under two years and pigs traditionally at around either 10 months or 17–21 months. The age of cattle and horses varied widely as the remains of both young and older animals were found. An exceptional find at Mineikiškės is a cattle metacarpal bone with exostosis on the distal end (Micelicaitė et al. 2023). This kind of pathology could indicate that the individual was used as a draught animal (Groot 2005).

The composition of domestic animal remains at both sites, together with the rest of the Late Bronze Age sites in eastern Lithuania, is similar to contemporaneous zooarchaeological material from the northeastern part of modern Belarus, where bones of pigs and small ungulates in general were the most numerous at Late Bronze Age sites (Egoreichenko 2006; Luik et al. 2022; Luchtan 1986). In contrast, the zooarchaeological material from western Lithuania is dominated by cattle and horse remains, suggesting differences in animal husbandry strategies between eastern and western Lithuania in the Late Bronze Age (Bliujienė et al. 2020).

Meanwhile, in the surrounding area, a different kind of animal husbandry developed. In Scandinavia, Germany and the Lusatian culture in Poland, cattle remains are generally more abundant than in Lithuania, accounting for 40%–60% of the total faunal remains. In western Lithuania, western Latvia and continental Estonia, the proportion of cattle is also higher than in eastern Lithuania, with the percentage being around 30% or more (Graudonis 1989; Harding 2000; Kveiborg 2018; Maldre 2008; Micelicaitė et al. 2023; Vasks et al. 2011 and 2019).

Horses are another interesting case. The attribution of horse remains to either wild or domestic animals, along with their function, is still heavily debated. Horse remains accounted for 5.3% of the identified mammal remains at Mineikiškės and 1.3% at Garniai I. As already mentioned, this is significantly lower compared to Late Bronze Age and Roman Iron Age (ca. 1–400 AD) sites in western Lithuania (Bliujienė et al. 2020), although in other cases, e.g. the Šventoji 43 Subneolithic settlement, the proportion of horses was as high as 2.1% (Piličiauskas et al. 2019a). Like those of other animals, horse bones at Mineikiškės and Garniai I have butchering marks. However, their anatomical composition and the size of the fragments compared to other species is remarkable. Although various parts of the skeleton were found, 66.4% of the horse remains at Mineikiškės were head bone fragments and teeth. At Garniai I, this percentage was a little lower (42.9%). By contrast, head bone fragments and teeth of other large domestic ungulates, i.e. cattle, accounted for 44.9% at Mineikiškės and 40.6% at Garniai I. Moreover, the average horse skeletal fragment found in Mineikiškės (excluding single teeth) weighed 27.3 g, compared to 12.1 g for cattle. At Garniai I, the average weight of horse bone fragments (excluding teeth) was 20.3 g, compared with 8.1 g for cattle. The age of the horses varied widely — from a foal less than a year old (Figure 4) to an animal of 2.5–3.5 years old to an old individual of about 20 years (Micelicaitė et al. 2023). Another important piece of evidence comes in the form of a P_2 tooth with bit-wearing traces. This could indicate that at least some of these animals were used for horseback riding. This would not be surprising, as fragments of cheek-pieces of horse harness are known from other Bronze Age fortified settlements and burial sites in the eastern Baltic (Maldre and Luik 2009). However, other anatomical features, depositional contexts, the age of the animals and butchering marks do not permit an in-depth analysis of the primary function of the horse, nor their attribution as either wild or domestic animals. Still, it is evident that horses were butchered in a particular manner. While more research is necessary, this could suggest that in the Late Bronze Age this animal had already attained an exceptional status throughout what is modern-day Lithuania (Bliujienė et al. 2017; 2020).

In addition to domestic animals, the remains of wild game were also found at both sites. Among these, bones of small game — hare and fox alongside mustelids and red squirrels —prevailed, while the remains of large game were less numerous (Tables 5 and 6). Although the importance of fur game hunting has been pointed out by previous researchers (Luchtan 1986), the available data from Mineikiškės and Garniai I would not support the significance of this, even if such practices as *schlepping* are considered. On the other hand, except for at the Subneolithic sites Kretuonas 1C and 1D, where remains of martens are present in proportions of 8%–14%, bones of fur game are also scarce at other prehistoric and historic sites (Daugnora and Girininkas 2004; Piličiauskienė and Blaževičius 2018; Piličiauskas et al. 2019a). Therefore, it would be difficult to make assumptions about the scale and importance of fur game hunting based only on the bones. Whatever the case,

Table 6. Taxonomic and anatomical distribution of animal remains from Garniai I hilltop site. NISP = number of identified specimens, MNI = minimum number of individuals. Data from this study and Micelicaitė et al. 2023.

Animal/bone	**Horncore**	**Skull**	**Mandible**	**Teeth**	**Vertebrae**	**Scapula**	**Humerus**	**Radius**	**Ulna**	**Metacarpus**	**Carpal bones**	**Pelvis**	**Femur**	**Tibia**	**Fibula**	**Tarsal bones**	**Metatarsus**	**Phalanges**	**Metapodias**	**NISP**	**NISP, %**	**MNI**	**MNI, %**
Catlle *Bos taurus*	2	2	1	8			4	2	2	2	1		3	3				1	1	**32**	**6,0**	**2**	**5,9**
Sheep *Ovis aries*																1	1			**2**	**0,4**	**4**	**11,8**
Sheep/goat *Ovis aries / Capra hircus*		13	3	29	12		1	17		3	3	2	15	10		3	7	7	2	**127**	**23,9**		
Pig *Sus scrofa domesticus*		40	6	94	19	2	14	7	2	5	10	1	24	7	8	2	1	50	15	**307**	**57,8**	**16**	**47,1**
Horse *Equus ferus ferus / E. f. caballus*				3	3			1												**7**	**1,3**	**2**	**5,9**
Dog *Canis familiaris*				1																**1**	**0,2**	**1**	**2,9**
Boar *Sus scrofa scrofa*															2					**2**	**0,4**	**1**	**2,9**
Boar / pig *Sus scrofa scrofa / S. s. domesticus*				2																**2**	**0,4**	**1**	**2,9**
Mountain hare / European hare *Lepus timidus / L. europaeus*				1	2	1	4	3	1	1		1	3	11		2			1	**31**	**5,8**	**1**	**2,9**
Brown bear *Ursus arctus*																1				**1**	**0,2**	**1**	**2,9**
Red fox *Vulpes vulpes*			1		3							2	1				1			**8**	**1,5**	**1**	**2,9**
European marten *Martes martes*					1															**1**	**0,2**	**1**	**2,9**
European polecat *Mustela putorius*				1	1															**2**	**0,4**	**1**	**2,9**
Red squirrel *Sciurus vulgaris*							2													**2**	**0,4**	**1**	**2,9**
Small rodents		2	2	1								1								**6**	**1,1**	**1**	**2,9**
In total	**2**	**57**	**13**	**140**	**41**	**3**	**25**	**30**	**5**	**11**	**14**	**7**	**46**	**31**	**10**	**9**	**10**	**58**	**19**	**531**		**34**	
In total, %	**0,4**	**11,1**	**2,5**	**27,2**	**8,0**	**0,6**	**4,9**	**5,8**	**1,0**	**2,1**	**2,7**	**1,4**	**8,9**	**6,0**	**1,9**	**1,7**	**1,9**	**11,3**	**3,7**		**100,0**		**100,0**

Figure 4. Foal mandible with butchering. (Photo by Piličiauskienė).

the small number and diversity of wild animals would suggest that hunting did not play a significant part in the economy and diet of local communities.

The situation with fishing is somewhat similar. As already mentioned, only 287 fish bone fragments (excluding scales) were discovered, which amounted to 3.6% of all zooarchaeological material. Among these, the remains of at least six freshwater species were identified. The most numerous were cyprinids (65.1%), which were represented mostly by rudd (*Scardinius erythrophthalmus*), bream (*Abramis brama*) and less abundant bones of roach (*Rutilus rutilus*), ide (*Leuciscus idus*) and chub (*Leuciscus cephalus*). Remains of pike (*Esox lucius*) (28.4%) and perch (*Perca fluviatilis*) (5.6%) were also discovered (Micelicaitė et al. 2023). The percentage of fish at Mineikiškės is relatively high compared to Garniai I and other Late Bronze Age sites (e.g. Sokiškiai, Narkūnai) in eastern Lithuania (Danilčenko 1983; Luchtan 1986). However, these results are affected by the excavation techniques used in legacy excavations where dry sieving was not used.

On the other hand, compared to the Subneolithic (e.g. Šventoji 4, 43, Kretuonas C and D) (Piličiauskas et al. 2019a, 2019b; Piličiauskienė, unpublished data), the number of fish remains found in the Late Bronze Age sites is very low. This is a clear reflection of the overall decline in fishing and fish consumption which is already evident in the Late Bronze Age material. It is worth noting that in contrast to the Mesolithic and Subneolithic, from the Late Bronze Age onward fishing did not play an important role in the economy and diet of local communities (Piličiauskas et al. 2017a; 2017c). Fish was insignificant in the human diet during the Late Bronze Age and Roman and Migration periods, as demonstrated by δ^{13}C and δ^{15}N stable isotope analysis of human collagen (Simčenka et al. 2022, 2023) and pottery foodcrust analysis (Podėnas et al. 2023).

3.4. Stable isotope evidence

A total of 55 charred cereal remains were analysed. Plant samples were subdivided into groups based on the taxonomy and site of origin (Table 4). Chronological division was not possible due to samples falling within the Hallstatt radiocarbon plateau, thus changes over time could not be tracked. Results of δ^{13}C and δ^{15}N measurements of crops are presented in Fig. 5.

The δ^{15}N values of barley range from 2.8‰ to 7‰, the values of emmer from 3.5‰ to 5.2‰, the values of spelt from 4.2‰ to 5.6‰, and the values of millet from 4.3‰ to 8.9‰. The δ^{13}C values of barley range from -28‰ to -23.7‰, the values of emmer from -26.2‰ to -23.4‰, the values of spelt from -25.1‰ to -23.3‰ and the values of millet from -12.8‰ to -10.4‰. The most notable difference is the δ^{13}C values of millets compared to C_3 cereals (barley and wheat). This is caused by different photosynthetic pathways during which C_4 plants discriminate against atmospheric $^{13}CO_2$ less than C^3 plants, yielding higher δ^{13}C values compared to C_3 plants (Liu et al. 2012). The overall δ^{15}N values of *Panicum* also appear to be higher. The sample size is too small to detect any significant differences, yet similar patterns have been observed in other parts of Bronze Age Europe (e.g. Varalli et al. 2021). Also, it is worth noting that δ^{13}C values of barley from the Gediminas Hill assemblage are generally lower than those of wheat, but the differences fall within the 1‰–2‰ range. This is typical for these species grown in similar watering conditions (Wallace et al. 2013), thus it likely indicates a similar irrigation regime for the cultivation of barley and wheat.

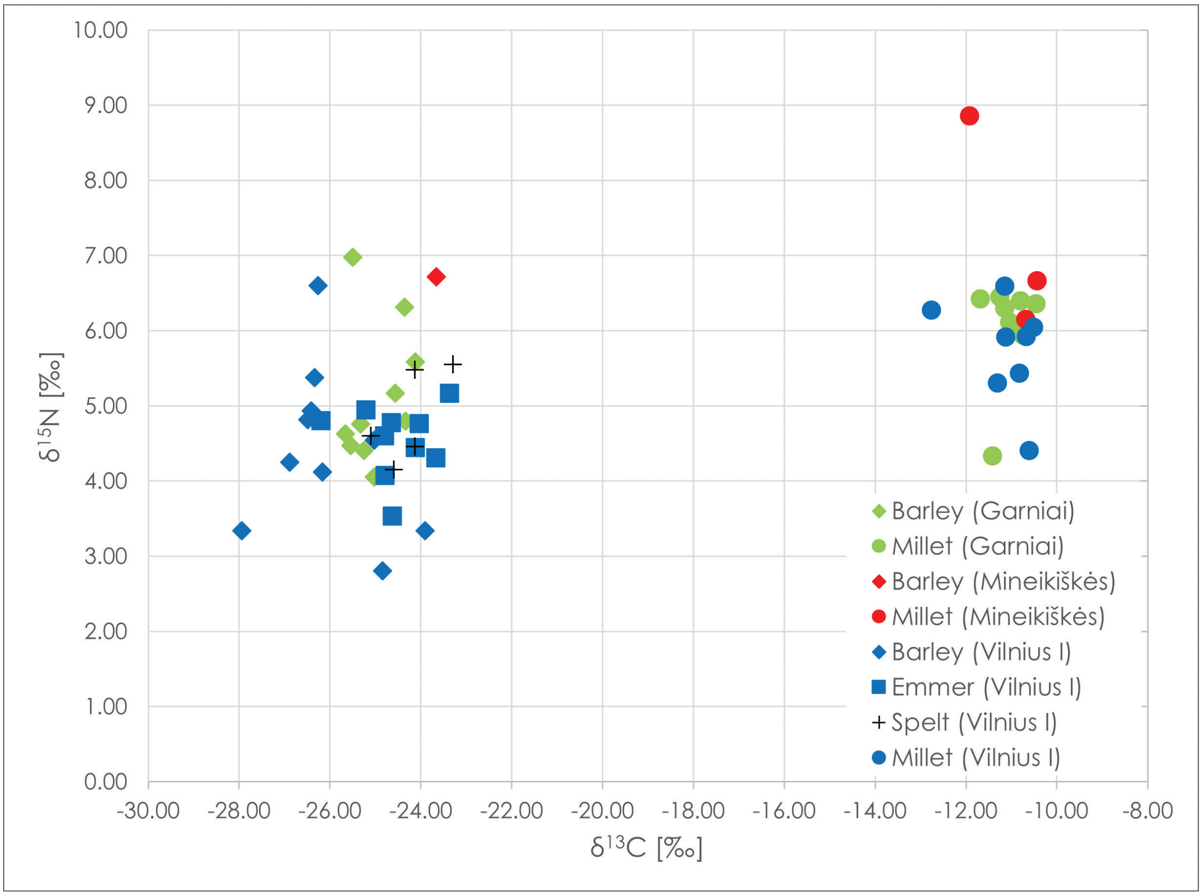

Figure 5. Stable carbon and nitrogen isotope ratios for archaeobotanical remains. Corrected $\delta^{15}N$ (-0.31‰) and $\delta^{13}C$ (-0.11‰) values have been used to offset the charring effect.

When comparing $\delta^{15}N$ for different sites (Fig. 6), barley samples from Garniai I (5.12‰ ± 0.92‰, n=10) tend to have higher values compared to barley from Gediminas Hill (4.41‰ ± 1.11‰, n=10). Mineikiškės is only represented by a single data point, with $\delta^{15}N$ value of 6.72‰. Similar patterns are also observed amongst millets. *Panicum* samples from Garniai I have higher $\delta^{15}N$ values (6.04‰ ± 0.71‰, n=8) than those from Gediminas Hill (5.74‰ ± 0.68‰, n=8), whereas millets from Mineikiškės have the highest values (7.23‰ ± 1.44‰, n=3). Emmer and spelt grains were only recovered from the Gediminas Hill assemblage. $\delta^{15}N$ measurements of *Triticum dicoccon* and *Tr. spelta* returned comparative results (4.54‰ ± 0.48‰, n=10 and 4.85‰ ± 0.63‰, n=5 respectively), with values of spelt being slightly elevated.

The debate over the crop management strategies during the Late Bronze Age in the southeastern Baltic is still ongoing. It has been suggested that local farmers relied on extensive farming, such as slash-and-burn agriculture, characterised by low labour input, exploitation of natural resources and degradation of landscape (e.g. Girininkas 2013). In contrast, recent data indicates a more intensive form of farming (Minkevičius 2020; Minkevičius et al. 2020), possibly resembling a permanent or semi-permanent field cultivation characteristic of other parts of Late Bronze Age Europe. However, previously it was only possible to address this topic by analysing plant microremains (e.g. Stančikaitė et al. 2004; 2006) and macroremains (e.g. Antanaitis-Jacobs, et al. 2002; Pollmann 2014; Minkevičius et al. 2020). This considerably limited the depth of such inquiries, whereas stable N isotope data could provide some further insights into the discussion.

The $\delta^{15}N$ values are within the range between 2.8‰ and 8.9‰, with most of them being between 4‰ and 6‰ (5.23‰ ± 1.11‰, n=55), and values of *Panicum* being notably higher (6.10‰ ± 0.94‰, n=19). According to $\delta^{15}N$ values established by crop growing experiments (Bogaard et al. 2013), similar values are detected in crops from moderately manured fields and could indicate an intensive cultivation. This form of farming, while labour intensive, also preserves the environment, uses available resources strategically, and does not require constant relocation of the community in search of new arable land (Rowley-Conwy 1984). This is in agreement with the settlement patterns in Late Bronze Age Lithuania. Fortified settlements were usually inhabited for more than one or even several decades before the settlement was eventually relocated (Podėnas 2022), which attests to a sedentary lifestyle of

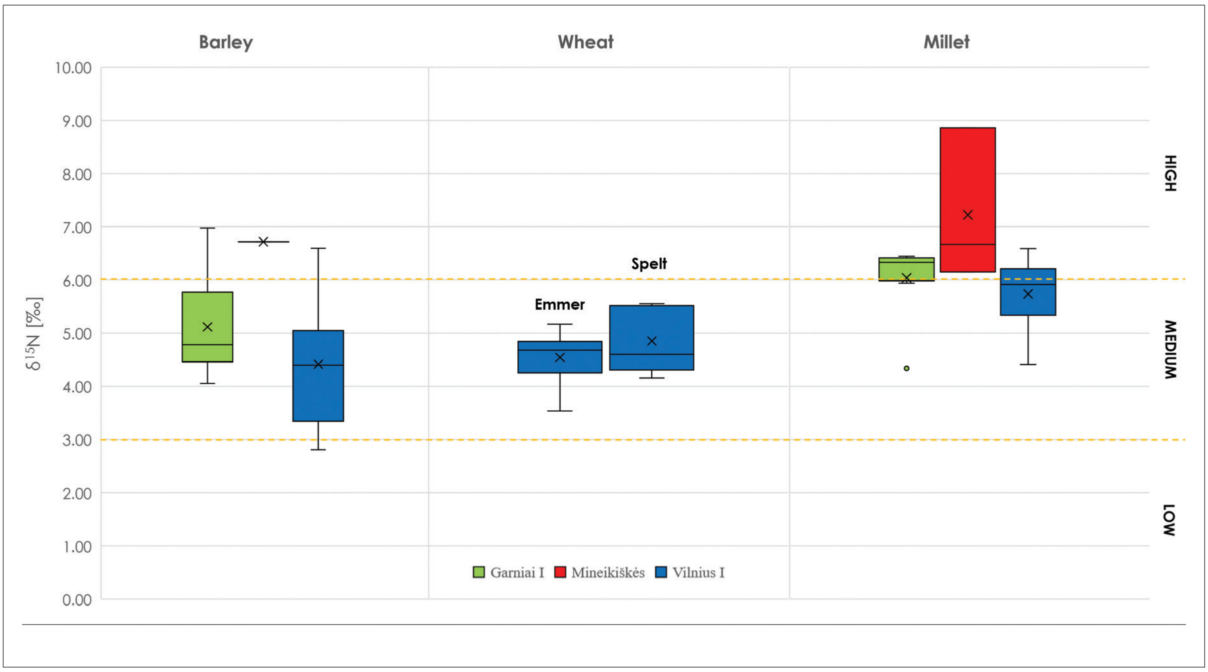

Figure 6. Nitrogen stable isotope composition for plant remains by site. Corrected δ^{15}N (-0.31‰) values have been used to offset the charring effect.

local farmers. The shift towards more intensive agriculture is further supported by the pollen record. Although securely dated palynological data from Late Bronze Age Lithuania is scarce, records indicate a spike in *cerealia*-type pollen alongside an increase in *Plantago lanceolata* (Stančikaitė et al. 2004; 2006; 2019) during this period. This could indicate the presence of permanent cultivation because, despite being an indigenous plant, *P. lanceolata* in prehistoric contexts is usually associated with fallow phases and grazing (Rösch 2013).

By comparison, carbon isotope values in plant tissues can be influenced by the availability of water, sunlight and other factors that could limit the photosynthetic rate (Mueller-Bieniek et al. 2019). Looking at δ^{13}C values for analysed sites, we can see that barley samples from Gediminas Hill (-26.03‰ ± 1.15‰, n=10) show marginally lower values compared to Garniai I (-24.97‰ ± 0.57‰, n=10). Mineikiškės is only represented by a single data point, with δ^{13}C value of -23.66‰. Also, δ^{13}C values of emmer (-24.55‰ ± 0.81‰, n=10) and spelt (-24.25‰ ± 0.67‰, n=5) from Gediminas Hill were higher than those of barley by ~1.5‰, which is to be expected for these species grown in similar watering conditions.

The Δ^{13}C values of analysed samples show no signs of water stress or sunlight deficiency and indicate only minor differences in growing conditions (Fig. 7). While some minor differences could be observed, these could be a result of either variation in the local environment or differences between growing seasons. However, further analysis of these questions is hindered by the relatively small sample size and chronological uncertainty due to the Hallstatt radiocarbon plateau.

In total, 33 animal bone samples of domestic and wild herbivores, omnivores, carnivores and fish from Mineikiškės (n=26) and Garniai I (n=7) sites were analysed (Table 7). However, here we primarily focus on the results obtained from domestic animals (cattle, sheep/goat, pig and horse). The δ^{13}C of the cattle (n=3) ranged from -21.02‰ to -21.37‰ and δ^{15}N from 5.05‰ to 5.9‰. All sampled individuals were adults. All sheep/goats (n=6) studied were also adults. Their δ^{13}C values are within the range between -21.01‰ to -21.98‰, and δ^{15}N varied from 4.45‰ to 7.32‰. The δ^{13}C values of pigs (n=8) fall within the range of -19.73‰ to -21.89‰, and δ^{15}N from 6.10% to 7.15%. Except for two individuals aged 8–9 months, the analysed pigs were older than one year.

When comparing the results with the δ^{13}C and δ^{15}N values of the early modern period animals (Simčenka et al. 2020; Skipitytė et al. 2020), only a slightly more negative δ^{13}C and enriched δ^{15}N values are observed in the later period. For Late Bronze Age and early modern period cattle (n=3), the mean δ^{13}C values were -21.17‰ ± 0.18 and -21.67‰ ± 0.4, while δ^{15}N was respectively 5.67‰ ± 0.54 and 6.30‰ ± 0.9. For sheep/goats, the mean δ^{13}C values in the Late Bronze Age were -21.37‰ ± 0.34 and in the early modern period -21.65‰ ± 0.36, while the mean δ^{15}N values were 5.63‰ ±1.2 and 6.05±1.52. Thus the difference in δ^{13}C stable isotope values for cattle was 0.50‰ and for sheep/goats 0.28‰ in the periods referred to. Meanwhile, differences in δ^{15}N values amounted to 0.63‰ for cattle and

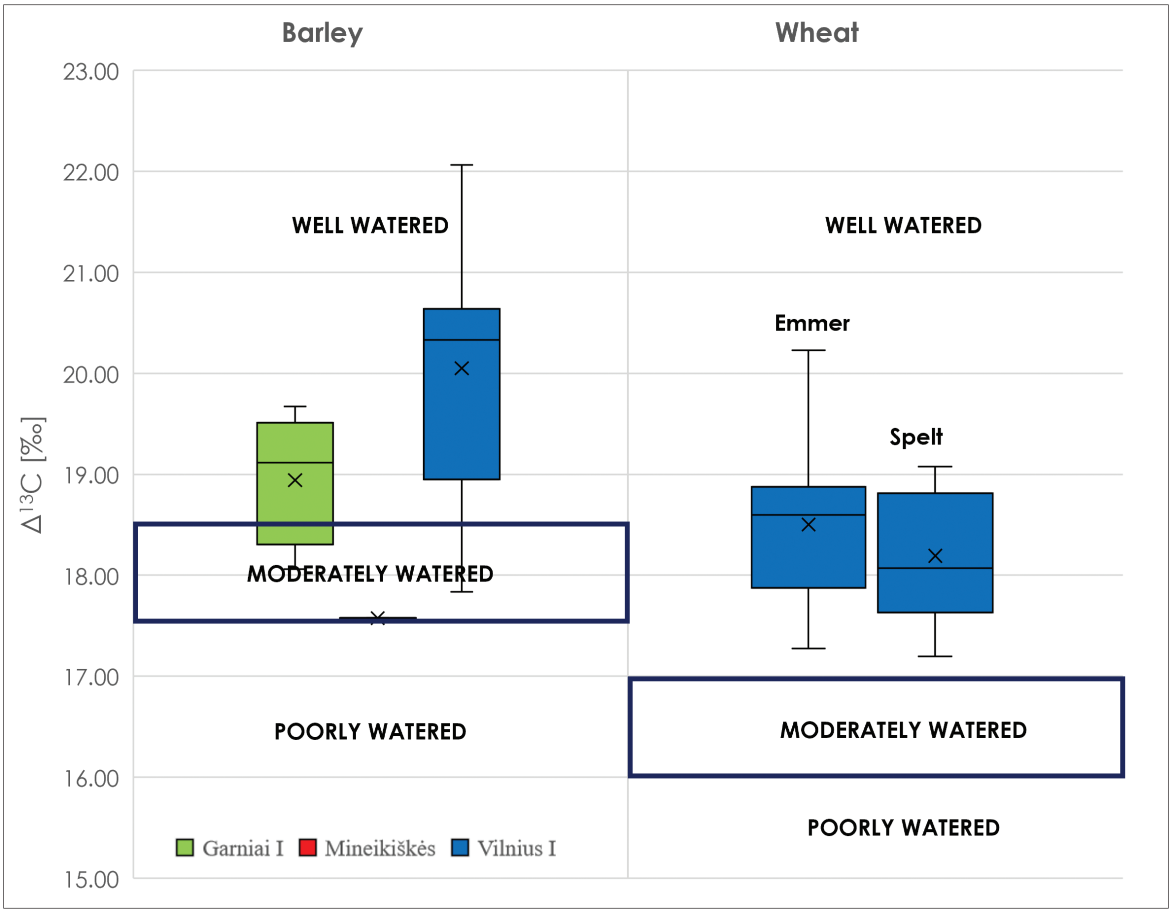

Figure 7. Carbon stable isotope composition for plant remains by site. Corrected δ^{13}C (-0.11‰) values have been used to offset the charring effect. Δ^{13}C values calculated using AIRCO2_LOESS data calibrator (Ferrio et al. 2005).

0.42‰ for sheep/goats. Such minor differences in δ^{15}N values for the Late Bronze Age and early modern period herbivores would suggest a similar diet and living environment. Since the early modern period fields were fertilised (Dundulienė 1963; Piličiauskienė and Blaževičius 2018), the δ^{15}N results for herbivores would further support the practice of manuring in the Late Bronze Age. Thus the results of the herbivore δ^{15}N analyses could also confirm the results of the crop analyses, suggesting a fertilisation of the fields in the Late Bronze Age.

The mean δ^{13}C values of Late Bronze Age and early modern period pigs were -20.80‰ ± 0.79 and -21.8‰ ± 0.77, while δ^{15}N values were 6.54‰ ± 0.39 and 7.58‰ ± 1.46, i.e. the differences amounted to 1.0‰ and 1.04‰ respectively. However, pigs are omnivores, and their diet is more strongly affected by humans than herbivores. Analysed early modern period pigs were sampled from two towns — Vilnius (eastern Lithuania, n=1) and Klaipėda (coastal Lithuania, n=3). Although pigs may have been bred outside the towns, the enriched δ^{15}N values of the animals from the coastal area may have been influenced by the higher presence of fish in their diet. Moreover, the abundant faeces in the diet of urban pigs may also contribute to the higher δ^{15}N values.

The average δ^{13}C (-21.4‰ ± 0.33) of Mineikiškės and Garniai I horses was 1.22‰ higher than the average δ^{13}C (-22.71‰ ± 0.5) values of Roman and migration period horses (n=12) from Lithuania, while δ^{15}N (5.09‰ ± 0.72) was lower by 0.64‰ (5.73‰ ± 1.0) (Piličiauskienė et al. 2022). The differences are minor and may have been influenced by the small number of Late Bronze Age horses sampled. On the other hand, the slightly enriched δ^{15}N in Roman and Migration period horses could reflect additional fodder and better diet or herding of horses in fertilised pastures (Piličiauskienė et al. 2022). Interestingly, the δ^{15}N value of a yearling foal was relatively low (5.97‰), considering the individual could still be lactating or be recently weaned. Lower δ^{13}C values of Late Bronze Age horses could be affected by the herding of horses in more open landscapes, thus avoiding a thicker canopy in which plants, due to the so-called canopy effect, tend to have more depleted δ13C values (Bonafini et al. 2013).

Table 7. Animal carbon and nitrogen stable isotope results and supportive information.

No.	Species	Site	Sample ID	δ^{13}C, ‰	δ^{15}N, ‰	%N	%C	C/N	C/N atomic	Specimen sampled	Age, size
1	Cattle *Bos taurus*	Mineikiškės	BE5	-21,02	5,98	15,66	43,41	2,77	3,23	maxilla, right	adult
2	Cattle *Bos taurus*	Mineikiškės	BE6	-21,37	5,99	13,94	39,56	2,84	3,31	P^3, right	adult
3	Cattle *Bos taurus*	Mineikiškės	BE12	-21,12	5,05	14,09	38,83	2,76	3,22	metacarpus, left	>1.5 y
4	Sheep / goat *Ovis aries* / *Capra hircus*	Mineikiškės	BE1	-21,91	4,55	15,52	43,21	2,78	3,25	mandible, right	>1.5 y
5	Sheep / goat *Ovis aries* / *Capra hircus*	Mineikiškės	BE2	-21,02	5,28	15,79	44,13	2,79	3,26	mandible, right	>1.5 y
6	Sheep / goat *Ovis aries* / *Capra hircus*	Mineikiškės	BE3	-21,37	4,45	16,16	44,64	2,76	3,22	mandible, left	>1.5 y
7	Sheep / goat *Ovis aries* / *Capra hircus*	Mineikiškės	BE4	-21,01	6,56	15,81	44,29	2,80	3,27	mandible, left	>1.5 y
8	Sheep / goat *Ovis aries* / *Capra hircus*	Garniai 1	BE7	-21,56	7,32	16,37	45,68	2,79	3,26	mandible, left	>1.5 y
9	Sheep *Ovis aries*	Mineikiškės	BE18	-21,28	6,70	15,00	41,07	2,74	3,19	mandible, right	4-5 mths
10	Pig *Sus scrofa domesticus*	Mineikiškės	BE8	-21,20	6,42	11,05	31,00	2,81	3,27	maxilla, left	>1.5 y
11	Pig *Sus scrofa domesticus*	Mineikiškės	BE9	-20,39	6,10	15,70	42,84	2,73	3,18	maxilla, right	>1.5 y
12	Pig *Sus scrofa domesticus*	Mineikiškės	BE10	-19,87	6,30	15,09	40,89	2,71	3,16	maxilla, right	>1.5 y
13	Pig *Sus scrofa domesticus*	Mineikiškės	BE11	-20,53	6,48	14,81	40,41	2,73	3,18	maxilla, left	>1 y
14	Pig *Sus scrofa domesticus*	Garniai 1	BE14	-21,22	7,08	13,48	36,98	2,74	3,20	maxilla, right	>1.5 y
15	Pig *Sus scrofa domesticus*	Mineikiškės	BE19	-19,73	7,15	15,36	42,03	2,74	3,19	maxilla, right	10-12 mths
16	Pig *Sus scrofa domesticus*	Garniai 1	BE31	-21,55	6,59	15,19	41,62	2,74	3,20	maxilla, right	10-12 mths
17	Pig *Sus scrofa domesticus*	Garniai 1	BE33	-21,89	6,18	14,68	40,12	2,73	3,19	mandible, left	7-9 mths
18	Horse *Equus ferus ferus* / *E. f. caballus*	Garniai 1	BE13	-21,72	5,11	14,70	39,93	2,72	3,17	vertebra cervical	
19	Horse *Equus ferus ferus* / *E. f. caballus*	Mineikiškės	BE16	-21,72	4,20	15,66	42,46	2,71	3,16	radius, right	>4.5 y
20	Horse *Equus ferus ferus* / *E. f. caballus*	Mineikiškės	BE17	-21,02	5,97	15,34	41,80	2,72	3,18	mandible, left	<1 y, M$_1$ to be erupted
21	Hare *Lepus timidus* / *L. europaeus*	Mineikiškės	BE20	-24,28	4,55	15,85	43,05	2,72	3,17	tibia, right	
22	Hare *Lepus timidus* / *L. europaeus*	Mineikiškės	BE21	-25,62	2,85	15,58	42,41	2,72	3,18	tibia, right	
23	Hare *Lepus timidus* / *L. europaeus*	Garniai 1	BE32	-22,78	2,75	15,50	42,15	2,72	3,17	humerus, left	
24	Brown bear *Ursus arctos*	Garniai 1	BE15	-21,18	4,74	15,78	42,80	2,71	3,16	calcaneus, right	
25	Fox *Vulpes vulpes*	Mineikiškės	BE22	-20,41	9,68	15,43	42,16	2,73	3,19	mandible, left	
26	Fox *Vulpes vulpes*	Mineikiškės	BE23	-19,71	9,23	15,96	43,11	2,70	3,15	mandible, left	

Table 7. Continuation

No.	Species	Site	Sample ID	δδ^{13}C, ‰	δ^{15}N, ‰	%N	%C	C/N	C/N atomic	Specimen sampled	Age, size
27	Rudd *Scardinius erythrophthalmus*	Mineikiškės	BE25	-22,95	7,35	15,78	44,11	2,79	3,26	pharyngeal, left	25-30 cm
28	Roach *Rutilus rutilus*	Mineikiškės	BE27	-18,92	3,85	15,86	44,80	2,83	3,30	pharyngeal (two left and one right)	two 20-25 cm, one 15-20 cm
29	Ide *Leuciscus idus*	Mineikiškės	BE29	-23,72	9,64	15,32	42,07	2,75	3,20	pharyngeal, left	35-40 cm
30	Chub *Leuciscus cephalus*	Mineikiškės	BE26	-25,98	8,29	15,87	43,28	2,73	3,18	pharyngeal, right	30-40 cm
31	Northern pike *Esox lucius*	Mineikiškės	BE30	-20,60	10,04	16,33	45,25	2,77	3,23	cleithrum and operculum right, vertebra	45-50 cm
32	Northern pike *Esox lucius*	Mineikiškės	BE24	-19,89	7,77	15,50	44,09	2,84	3,32	maxilla, left	60-70 cm
33	Perch *Perca fluviatilis*	Mineikiškės	BE28	-19,57	7,51	16,52	44,38	2,69	3,13	dentary, operculum, praeoperculum right, scales	25-30 cm

Conclusions

Archaeobotanical, zooarchaeological and stable isotope data analysed in this study present a more comprehensive picture of the nature of agriculture in the southeastern Baltic during the Late Bronze Age. Evidence suggests that local Bronze Age communities engaged in intensive forms of farming with an emphasis on tillage, soil fertilisation and cultivation of permanent fields. This is in line with other types of evidence from the same period, such as diversification of crops, changes in settlement patterns and landscape transformation.

The Late Bronze Age farmers are believed to have cultivated a diverse range of crops, with a keen focus on both productivity and risk management. These sedentary communities practised permanent field cultivation, which required constant maintenance through tillage and manuring, as opposed to slash-and-burn agriculture. Moreover, this approach had the added benefit of preserving the surrounding landscape. Animal husbandry was also a critical component of the local farmers' subsistence. While pigs and small ungulates were the primary focus, cattle and horses were also raised for their important role in farming. Cattle, for instance, were used as draught animals, and the animal manure was an essential fertiliser for the fields.

This closely mirrors the processes of Late Bronze Age agrarian intensification sweeping across northern Europe. New data presents a different framework for exploring changes in agriculture that started towards the end of the 2nd millennium BC and allows us to examine the cultural landscape of the Late Bronze Age southeastern Baltic from a new perspective. However, it is evident that in order to address the topic with regard to more nuanced changes over time, more data is needed. This is especially true if the hypothesis of the coexistence of alternative or hybrid farming strategies is to be explored. The current dataset is solely based on the evidence from fortified sites. Thus, in order to construct a more complex picture of Late Bronze Age agriculture, the focus should be shifted towards gathering new data from unenclosed settlements.

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Naujos įžvalgos apie Vėlyvojo Bronzos amžiaus (1100–400 m. pr. Kr.) Pietryčių Baltijos regiono bendruomenių gamybinį ūkį

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Santrauka

Straipsnyje pristatomi archeobotaniniai, zooarcheologiniai ir lengvųjų stabiliųjų C ir N izotopų matavimų duomenys ir trijų pastaraisiais metais tirtų Rytų Lietuvos Vėlyvojo Bronzos amžiaus (1100–400 m. pr. Kr.) piliakalnių – Garnių I, Mineikiškių ir Gedimino kalno. Tyrimai buvo atliekami 2020–2022 m. vykdant LMT mokslinių tyrimų projektą „Vėlyvojo Bronzos amžiaus (1100–500 m. pr. Kr.) ekonomika rytiniame Baltijos jūros regione: naujo modelio link“.

Tyrimų metu surinkti ir išanalizuoti 128 grunto mėginiai ir 10 280 gyvūnų osteologinės medžiagos fragmentų (4 lentelė, 3 pav.). Atlikti 55 skirtingų rūšių degusių kultūrinių augalų (paprastojo miežio, dvigrūdžio kviečio, speltos ir tikrosios soros) grūdų, 26 žinduolių (avies / ožkos, galvijo, kiaulės, arklio, kiškio, lapės ir meškos) ir 7 žuvų (raudės, kuojos, menkės, šapalo, lydekos ir menkės) kaulų $\delta^{13}C$ ir $\delta^{15}N$ matavimai (3, 7 lentelės). 14-a augalų liekanų ir du gyvūnų kaulai datuoti AMS ^{14}C metodu.

Archeobotaninės analizės rezultatai rodo, kad regiono bendruomenės vertėsi sėslia intensyvaus pobūdžio žemdirbyste, kuri buvo viena svarbiausių to meto ekonominių veiklų. Vietiniai žemdirbiai augino įvairius kultūrinius augalus, įskaitant skirtingas javų ir ankštinių augalų rūšis, pritaikytas vietos gamtinei aplinkai ir saugumui užtikrinti. Kaip ir Vakarų Lietuvoje, ekonomiškai svarbiausiomis to meto rūšimis laikytini miežiai ir soros, tačiau kartu auginta nemažai lęšių, žirnių, įvairių rūšių kviečių ir kitų žemė ūkio kultūrų.

Zooarcheologiniai tyrimai atskleidžia, kad gyvulininkystė vaidino ne mažiau svarbų vaidmenį. Vis dėlto, skirtingai nei Vakarų Lietuvoje, čia daugiausia buvo auginamos kiaulės ir smulkieji kanopiniai, tuo tarpu galvijai ir arkliai sudarė gerokai mažesnę dalį. Dorojimo žymės kauluose rodo, jog gyvuliai buvo svarbus maisto šaltinis, tačiau tuo jų ekonominė svarba neapsiribojo. Patologijų pėdsakai galvijų plaštakose atskleidžia, kad jie naudoti ir kaip darbiniai gyvuliai. Nedidelis laukinių gyvūnų ir žuvų kaulų skaičius rodo, kad šiuo laikotarpiu medžioklės ir žvejybos svarba jau buvo sumenkusi.

Stabiliųjų izotopų matavimai leidžia manyti, kad kultūriniai augalai buvo auginami palankiomis sąlygomis. $\delta^{15}N$ matavimais nustatyta, kad pasėliai greičiausiai buvo tręšiami gyvulių mėšlu (6 pav.), $\delta^{13}C$ vertės indikuoja, jog augalams nestigo drėgmės ir saulės šviesos (7 pav.). Ryškesnių skirtumų tarp pasėlių kultivavimo sąlygų skirtingose vietovėse nepastebėta. Stabiliųjų izotopų vertės naminių gyvulių kauluose leidžia manyti, kad jų mityba ir gyvenamoji aplinka galėjo būti panaši kaip ir naujaisiais laikais.

Šie duomenys ryškiai koreguoja Vėlyvojo Bronzos amžiaus ūkio vaizdą. Tikėtina, kad vietos žemdirbiai praktikavo ne ekstensyvią, kraštovaizdį alinančią, lydiminę žemdirbystę, o nuolatinių laukų kultivavimą, tipišką ir kitiems šio laikotarpio Baltijos jūros regiono kraštams. Galima manyti, kad su tokia žemdirbystės forma glaudžiai susijęs ir šiuo laikotarpiu itin išryškėjęs gyventojų sėslumas. Vis dėlto svarbu pažymėti, kad tuo metu matomas Vėlyvojo Bronzos amžiaus ūkio vaizdas išlieka gana vienpusiškas. Jis išskirtinai sąlygotas tik ankstyvųjų piliakalnių medžiagos, todėl nauji neįtvirtintų gyvenviečių duomenys galėtų atskleisti egzistavus ir kitokias ūkininkavimo strategijas.