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A Brief History of Broomcorn Millet Cultivation in Lithuania

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Abstract: The eastern Baltic region represents the world's most northerly limit of successful broomcorn millet (*Panicum miliaceum*) (hereafter, millet) cultivation in the past, yet this crop has been almost forgotten today. The earliest millet in the eastern Baltic region has been identified from macrobotanical remains which were directly dated to ca 1000 BCE. Between 800 and 500 BCE, millet was one of the major staple foods in the territory of modern-day Lithuania. Millet continued to play an important role in past agriculture up until the 15th century, with its use significantly declining during the following centuries. This paper analyses both the archaeobotanical records and written sources on broomcorn millet cultivation in Lithuania from its first arrival all the way through to the 19th century. The manuscript reviews the evidence of millet cultivation in the past as documented by archaeobotanical remains and historical accounts. In light of fluctuating records of millet cultivation through time, we present the hypothetical reasons for the decline in millet use as human food. The paper hypothesizes that the significant decrease in broomcorn millet cultivation in Lithuania from the 15th century onwards was likely influenced by several factors, which include climate change (the Little Ice Age) and the agricultural reforms of the 16th century. However, more detailed research is required to link past fluctuations in millet cultivation with climatic and historical sources, thus better understanding the roots of collapsing crop biodiversity in the past.

Keywords: archaeobotany; archaeology; history; broomcorn millet; Lithuania; climate

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1. Introduction

In this paper, we use the word "millet" to refer to the Broomcorn millet or Proso millet (*Panicum miliaceum*) species, which constitutes one of many other millet species cultivated across the world. However, only broomcorn millet was extensively cultivated as a human food in northeastern Europe, probably due to its fast vegetation period suitable for short summer months.

Together with foxtail millet (*Setaria italica*), broomcorn millet was domesticated in northern China between the 8th and 7th millennia BCE as inferred from phytolith analysis, while the earliest charred grains of broomcorn millet in an archaeological context in northern China date from the turn of the 7th–6th millennia BCE [1–3]. By 5000 BCE, almost all communities in northern China and their domesticated animals consumed C4 photosynthesis plants, likely domesticated millets [4–6]. Broomcorn millet was the first millet species that dispersed across Eurasia to become a highly influential crop in the ancient world outside of the rice-growing zone [7]. The earliest evidence of broomcorn millet outside the territory of present-day China is from the middle of the 3rd millennium BCE [8–11]. The pathways of early millet dispersal to Europe are not very clear, but current stable isotope and archaeobotanical data seem to indicate that broomcorn millet followed the Inner Asian Mountain Corridor across Central Asia before it reached Europe via the Caucasus or via Turkey to south east Europe [10]. Currently, the earliest radiocarbon dates directly derived from millet grains goes back to ca 1600 BCE and are from the southeast regions of Europe, from the territory of Ukraine [12–14]. The earliest stable isotope evidence of C4 plant consumers in Europe also comes from the territory of Ukraine [15]. Around the middle of the

2nd millennium BCE, the archaeobotanical record of millet in Europe suddenly increased in the quantity of grain found per site [13,16–18], while C4 plant consumption was also detected ubiquitously in human bone collagen for the first time [15,19,20]. Between the middle 2nd and the 1st millennia BCE, millet became one of the most important crops in central and northeastern Europe [21–29]. This dispersal of millet cultivation also coincided with the "Third Food Revolution" in Europe, which has been closely associated with an increased diversity of cultivated crops [30].

Broomcorn millet is an extremely relevant crop for food security, as some millet varieties complete their life cycle in a very short 40-day period [31], have the lowest carbon and water footprint of any cereal [32,33], and provide grains that are nutritionally more valuable than wheat, barley, and rice [34,35]. All cultivated millet species facilitate excellent risk management strategies for resource-poor farmers in marginal environments, and thus the United Nations Food and Agriculture Organization (FAO) declared 2023 the year of millets [36]. Nevertheless, despite its benefits of being an important source of human food or animal fodder, together with the immense environmental benefits, millet is almost a forgotten crop in Europe.

Studies on historical millet cultivation in northern latitudes are important for understanding how and why past populations maintained millet agriculture on the border of its geographical limits during the major climatic transformations and whether the cultivation of millet in these regions could be revived with the predicted rise in global temperatures. Along with climate, social and economic factors have played an important role in human choices of cultivars. Therefore, understanding the reasoning for millet fluctuation across time and space could help to tackle problems arising from food insecurity in the contemporary world.

This paper presents the dynamic use of millet as human food across time in Lithuania, which represents one of the most northerly countries in the world where millet was widely cultivated in the past. By reviewing the existing published and new datasets from the earliest millet remains in Lithuania across archaeological and historical times, we investigate millet use across time considering the possible reasons for fluctuations in its cultivation. Archaeobotanical datasets, direct millet dating results, and the analysis of historical sources provide an important glimpse into people's relationship with this crop across time.

2. Geographical Setting

Lithuania is situated on the eastern shore of the Baltic Sea between 56.27° and 53.53° latitude and 20.56° and 26.50° longitude. Any small changes in temperature on the geographical margins could influence the length of the millet growth season, thus affecting the overall success of this cereal.

Lithuania's terrain is an alternation of moderate lowlands and highlands. The highest elevation is 297.84 m above sea level. At present, Lithuania has a humid continental climate. Studies of crop physiology show that millet will not germinate at temperatures below 8–10 °C, and the optimal temperature for millet growth is between 25 and 30 °C [37,38]. Such temperatures in Lithuania currently only occur during the middle of June, and the first frost could happen early in October, which leaves up to 4 months for the millet vegetation period. There are 12 major groups of soils in Lithuania: Regosols, Leptosols, Cambisols, Luvisols, Planosols, Albeluvisols, Arenosols, Podzols, Gleysoils, Histosols, Fluvisols, and Anthroposols. Preliminary estimates show that Albeluvisols occupy 30% of the country, Luvisols 27%, Cambisols (13%), Arenosols (12%), Podzols (11%), mainly in forest areas, and Gleysols and Histosols (5.3%) in the depressions [39]. The most fertile soils in Lithuania are in the middle lowland zone, and the least fertile soils are in the sandy eastern zone [40]. As millet does not require particularly fertile soil for successful growth, soil acidity could strongly influence the yield in most millet species as higher pH is better tolerated [41–43]. Therefore, the patches of more alkaline soils could have been chosen in the places across Lithuania where millet cultivation took place.

3. Archaeobotanical Evidence of Millet Cultivation in Lithuania

This section focuses on millet archaeobotanical evidence published in the literature along with primary data on millet from various sites across Lithuania. The main selection criteria of site inclusion in this review were the presence of direct radiocarbon dates of millet plants or of other cereals that were found in close association with millet remains (Supplementary Material S1 and S2).

The broomcorn millet crop is among the earliest cultivated crop species in the territory of Lithuania that was introduced from the south just a few hundred years later than the earliest known cultigens (Table 1; Figure 1). Agriculture in Lithuania is an unusually late phenomenon that started very slowly, only around 1300 BCE [44], and became predominant during the Late Bronze Age, around 1100 BCE, with the rise of fortified settlement sites [45,46]. During this period, the dominant cultivars were Broomcorn millet, glume wheats (*T. spelta* and *T. dicoccum*), hulled and naked barley varieties (*Hordeum vulgare* subsp. *vulgare* and *Hordeum vulgare* subsp. *nudum*), some legumes, and false flax (*Camelina sativa*) [46–48].

Broomcorn millet is one of the ubiquitous crop species in the Late Bronze agricultural package of Lithuania. It has been identified at a majority if not all Late Bronze Age archaeological sites. Millet cultivation in the territory of Lithuania started *ca* 1100 BCE-just over a hundred years later than its earliest appearance in northern Germany at *ca* 1200 BCE [23], showing the extremely fast northernly dispersal of this crop. The earliest millet in Lithuania was found in the central Lithuanian sites of Karveliškės and Tarbiškės. A broomcorn millet caryopsis from the Karveliškės settlement was directly dated to 1011–904 cal BCE [46], while another from the Tarbiškės site was dated to 1124–931 cal BCE [49] (see Table 2, Figure 2). The millet grains at archaeological sites of southern Lithuania at Vingrėnai were also directly dated to the final Bronze Age period. The central plains of Lithuania contain the richest soils that probably facilitated other crops together with millet spread and further dispersal to eastern Lithuania's highlands.

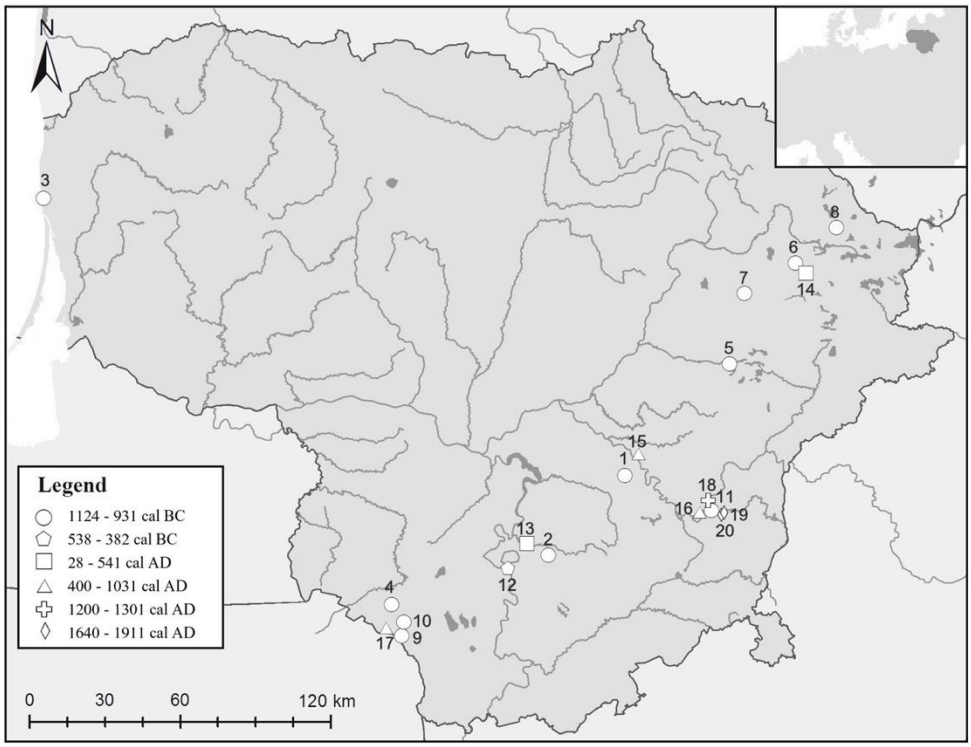

Figure 1. The locations of millet discoveries in Lithuania categorized according to the chronology of their cultivation. The site locations corresponding to numbers on the map are listed in Table 1.

Millet caryopses were ubiquitously found at fortified settlement sites and lakeside dwelling sites that were established in the highlands of eastern and southeastern Lithuania (Figure 1). A few sites could be mentioned, such as the Garniai I fortified hillfort dated to 792–540 cal BCE or Mineikiškės (793–548 cal BCE) [45,46,50]. A pottery vessel at a Late Bronze Age Narkūnai hillfort in northeast Lithuania contained a bottom with numerous millet fruit impressions, while stable isotope analysis of bulk organic residue from within the internal walls of pots from the Narkūnai site resulted in elevated $\delta^{13}C$ values indicative of C4 photosynthesis plant cooking, likely belonging to broomcorn millet [51]. At the Luokesa lakeside dwelling site in eastern Lithuania, millet chaff together with false flax chaff and other cultigens constituted an extensive organic-rich cultural layer [47].

An important landmark in Vilnius City in eastern Lithuania is Castle Hill, which served as a Late Bronze Age settlement where millet grains were also found together with other crops of the Bronze Age package [52].

The most obvious reason for the concentration of millet finds in eastern Lithuania is the greater number of archeological excavations that targeted hilltop sites, well visible in the landscape. Most of those sites constitute a part of the eastern Baltic Uplands (Highlands) that were formed by glacier fluctuation between 25,000 and 12,000 years ago [53]. The settlement sites in central Lithuania, on the other hand, remain poorly investigated as this region still requires an extensive archaeological survey for the identification and excavation of sites.

The Kukuliškiai site is the only hilltop site located on the shore of the Baltic Sea in western Lithuania. The archaeobotanical research there has also identified large numbers of broomcorn millet caryopses dated to 887–406 cal BCE [54].

The Turlojiškė site in southwest Lithuania also stands out from the other sites of the 1st millennium BCE as waterlogged millet caryopses there were identified at lacustrine deposits (Figure 2). The macroremains of millet dated to between 799 and 517 cal BCE were also recovered alongside the human remains dispersed in non-anatomical order [55]. The stable isotope analysis of bone collagen of these human remains has shown the consumption of C4 crops, probably millets, as a major human staple food at the Turlojiškė site [56–58].

Table 1. The list of sites that contain direct radiocarbon dates of millet remains from Lithuania or where the dating was done on other material associated with millet contexts.

Numbers in Figure 1	Site Name	Cal BCE/AD (2σ)	References
1	Tarbiškės	1124–931	[49]
2	Karveliškės	1011–904	[46]
3	Kukuliškiai	887–431	[54]
4	Turlojiškė	904–486	[56]
5	Luokesa	625–535	[47]
6	Garnia	792–540	[45,46]
7	Narkūnai	796–550	[45,51]
8	Mineikiškės	793–548	[45,46]
9	Vingrėnai	810–548	primary
10	Dzūkai	250–410	primary
11	Vilnius Castle Hill	800–500	[52]
12	Panemuninkai	538–382	primary
13	Grikapėdis	28–235	primary
14	Antilgė	34–245	[46]
15	Kernavė, Aukuro Hill	408–541	primary
16	Vilnius Castle Hill	400–900	[52]
17	Strumbagalvė	896–1031	primary
18	Vilnius Castle Hill	1200–1300	[52]
19	Pylimo g. 7, Vilnius	1697–1911	primary
20	Liejyklos g. 8 Vilnius	1640–	primary

During the final stages of the Early Iron Age through the Roman period, the importance of millet decreased slightly, although evidence of its cultivation was still found at several

sites, such as Antilgė, dated to between cal AD 34 and 245, pointing to its continuous use [46]. Unlike the Bronze Age, not all archaeobotanically investigated sites from this period show millet cultivation. For example, in Gabrieliškės (cal AD 125–320), Aukštadvaris (cal AD 210–406), Lieporiai, and other sites [46] no macroremains of millet were found, showing its sporadic use during this period. On the other hand, it is also possible that a larger sample size from sites where millet was absent would result in its presence.

The continuity of millet cultivation across time in Lithuania could be seen in later period sites. The archaeological excavations by A. Luchtanas at Aukuras Hill in Kernavė yielded rich archaeobotanical remains recovered from a clearly identified archaeological horizon that formed as a result of a single fire event that destroyed several buildings. Inside one storage building, *Triticum dicoccum*, *T. spelta*, *T. aestivum*, and barley (*Hordeum vulgare*, *H. vulgare* var. *nudum*) remains with millet (*Panicum miliaceum*) were identified. Millet constituted a major crop species in these archaeobotanical assemblages. The bread wheat caryopsis from this assemblage was dated to cal AD 408–541 (UBA-30595 1619 ± 29) (Table 1).

Macrobotanical remains of millet were identified in the layers of Vilnius Castle Hill dated to between AD 400 and 900, and between AD 1200 and 1400 [52]. The archaeobotanical research in the Lower Caste territory of Vilnius also yielded very well-preserved waterlogged millet paleae and lemma remains found in an animal stable dated to the mid-13th century, which is clearly indicative of millet use not only as human food but also as animal fodder [59].

The direct radiocarbon dates of millet grains or grains affiliated with millet assemblages point towards the continuous use of millet across Lithuania until the 15th century (Figure 2). The earliest written sources mentioning the use of millet are from the 14th and 15th centuries (see below). In later periods, after the 15th century, archaeobotanical discoveries of millet are rare and low in number, while direct radiocarbon dates are absent from later periods except in two cases (see Tables 1 and 2, Figure 1, Supplementary Material S1 and S2). After hundreds of archaeobotanically analyzed sites, mainly in Vilnius City, millet remains were found in just a few locations. A waterlogged millet fruit, that was found in the 18th-century layers of Vilnius Pylimo St. 7, was subjected to direct radiocarbon dating, resulting in a wide chronological range from cal AD 1697 to 1911 ((FTMC-JY48)-2 (1 ± 27)), and one from Liejyklos 8 in Vilnius resulted in a date of cal AD 1640 ((FTMC-JY48–6) (AD 222 ± 28)). In the other quarters of Vilnius City, such as in Rusų St. 5, millet palea and lemma remains were also identified in a cattle stable that was dated only with artefactual affiliations to the 17th century AD [60]. The former location was inhabited by tradesmen. Archaeobotanical research there identified the consumption of various imported exotic plants, such as olives, grapes, and figs [60]. Therefore, the millets among those plants could have also been imported with other goods from more southern regions of Europe.

Table 2. The radiocarbon dates obtained by directly dating broomcorn millet from various archaeological sites across Lithuania.

Site Name	Laboratory Number	Age_Uncal (y BP)	±1s (y)	Cal BCE/AD (2σ)	Reference
Karveliškės	UCIAMS-219321	2805	20	1011–904	[46]
Dzūkai	FTMC-JY48-1	1722	28	250–410	primary
Pylimo g. 7, Vilnius	FTMC-JY48-2	1	27	1697–1911	primary
Grikapėdžiai	FTMC-JY48-3	1898	39	28–235	primary
Vingrėnai	FTMC-JY48-4	2567	39	810–548	primary
Stumbragalvė	FTMC-JY48-5	1055	28	896–1031	primary
Liejyklos g 8 Vilnius	FTMC-JY48-6	222	28	1640–	primary
Panemuninkai	FTMC-JY48-7	2353	30	538–382	primary
Turlojiškė	Ua-16681	2590	75	904–486	[56]
Tarbiškės	FTMC-UU26-10-1	2868	26	1124–931	[49]

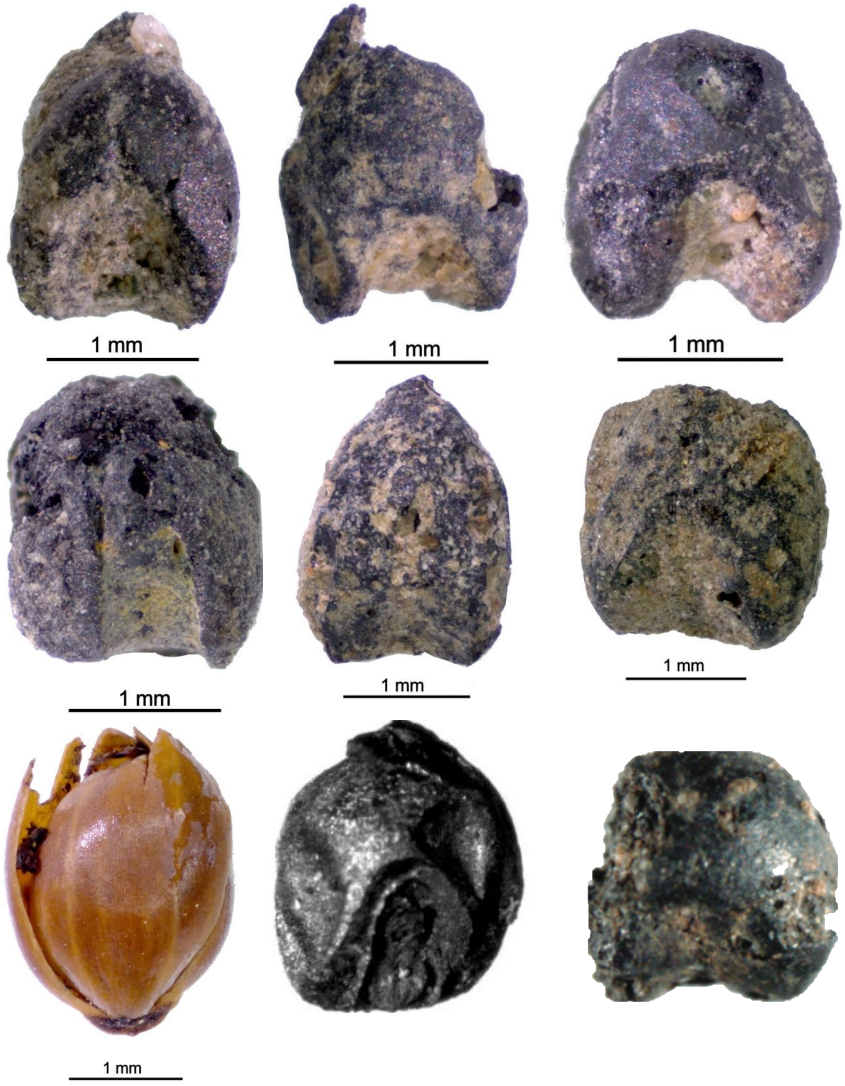

Figure 2. The directly dated millet caryopses and fruits from multiple sites across Lithuania. Top row: Dzūkų, Grikapėdžio, and Panemuninkai; middle row: Liejyklos g. 8 Vilnius, Stumbragalvė, and Vingrėnai; bottom row: Pylimo 7, Turlojiškė after [57], p. 56, and Tarbiskės after [49], p. 166. Scale bar: 1 mm.

4. Millet Etymology

In Lithuanian written sources from the 14th to the 20th century, the name millet appears in four main languages. In Latin it is called 'milium'; in Polish—'proso' (referring to the plant and its seeds) and 'jagły', 'iagły', or 'yagły' (referring to the groats made from it or millet dishes); and in Lithuanian—'sora' [61]. In the Slavonic administrative (chancellery) language of the Grand Duchy of Lithuania, the plant is called 'просо' [62]. The Baltic (Lithuanian "sora" and Latvian "sûra" and "sāre") name of the plant has attracted the attention of linguists because of its specific, non-typical form of the word which has no equivalent in other language groups of the region. Therefore, it was suggested that this word is associated with the pre-Indo-European or Proto-Indo-European linguistic stratum [63,64]. Others have noted that, except for 'hemp', 'millet' is the only cultivated crop word in the Baltic language which seems to have an eastern skew, being shared only with the Mordvinic, Komi, or Udmurt languages of the Volga region [65]. The Lithuanian word for millet, "sóra", unlike the Latv. "sûra", is irregular, which might suggest late or local origin of this word (Personal communication, Dr. Anthony Jakob, 16 November 2020) [66].

It is also important to note that the word 'sora' has historically been used in the Lithuanian language to refer to other small seeded grasses and spices, such as the hairy crabgrass (*Digitaria sanguinalis*), cockspur grass (*Echinochloa crus-galli*), wood millet (*Milium effusum*), mustard (*Sinapis*), meadow-grass (*Poa*), and water manna grass (*Glyceria fluitans*) [67]. Therefore, when analyzing written historical sources, it is important to take into account the context in which a particular term is mentioned.

5. Historical Sources

Written sources from the late 14th and early 15th centuries show that millet was a fairly common food in Lithuania and Poland at that time. In the account books of the court of the Polish king and Grand Duke of Lithuania, Jogaila (Jagiełło, ~1351–1434) millet use was mentioned in several cases. For example, millet was served at the tables of Jogaila's courtiers (e.g., "*procuratori et viceprocuratori cum familia*"), to the court masters of the hunt from Lithuania ('*Lytwanus venator*' or '*Litwanis venatoribus*'), and to the monarch himself. In these court accounts, millet is mentioned together with other foodstuffs grown on the ruler's manors and consumed from these manors as food together with cabbage (including pickled cabbage), poppy seeds, cannabis seeds, peas, chicken, beer, bread, and butter [68].

However, in the 16th and 17th centuries, out of 341 manor inventories reviewed, millet was mentioned only in a few manors, such as Bielica (Radziwill's manor) at the end of the 16th century; Varnionys (Čižas's manor) in AD 1560; Molodechno (Šemeta's manor) in AD 1623; Jalowa (Sapieha's manor) in AD 1623; in the list of revenues and expenditures of Radziwill's manors in AD 1636 [69]; the manor of Ona Daugėlaitė in the Vilkija region in AD 1539; Ilgiai manor in AD 1598; and the Rokiškis parish in AD 1563 [70]. In the late 16th and early 17th centuries, several varieties of millet were cultivated in Lithuania and Poland. According to Syrennius "...there are three kinds of (assuming broomcorn millet) varieties here and in the surrounding countries—red, white and black. The red ones are the most common, while the white and black ones are less..." [71]. The same three varieties of millet are also mentioned in agriculture books until the 19th century AD [72].

The quantities of millet in manor fields and granaries mentioned in 16th-century Lithuanian written sources are much lower than the quantities of other cereals. This situation is also confirmed by research carried out by Polish scholars. The percentage distribution of cereals in the fields was as follows: winter rye—54%; oats—26%; buckwheat—7.1%; barley—4.8%; spring wheat—4.1%; wheat—3.45%; and only a small area was sown with millet [73]. A similar situation was noted in the other manors where millet is mentioned, but not sown, sown in very small quantities compared to other cereals, or not mentioned at all (Tables 3 and 4). At the Bielica manor, however, millet still played an important role as a crop. Interestingly, here, a different method was used to calculate the amount of grain, not by the amount of clean (threshed and cleaned) grain, but by the number of bundles harvested (Tables 3 and 4). Depending on the annual crop yield, the same number of bundles yielded completely different quantities of grain. In other grain lists of the 16th-century manors (e.g., Radziwill's manor Dubingiai), we find mentions of millet, but the quantity of grains is marked as zero.

Table 3. The mentions of millet cultivation in the 16th–17th centuries.

Location	Manor Owner	Date AD	Source
Bielica	Radziwill	16th century	16th century
Varnionys	Čižas	1560	[69]
Molodechno	Šemeta	1623	[69]
Jalowa	Sapieha	1623	[69]
Vilkija	Daugėlaitė	1539	[70]
Ilgiau	-	1598	[70]
Rokiškis	parish	1563	[70]

Table 4. Quantities of different cereals sown at Daugilaitės, Rokiškis, Ilgiai, and Bielica manors in the 16th century.

	Manor			
Cereal Species Sown	**Daugėlaitė's in Vilkija Region (in Liters)**	**Rokiškis (in Liters)**	**Ilgiai (in Liters)**	**Bielica (in Bundles)**
Winter rye	~864	~814	~12,617	1226
Summer rye	---	~475	~814	165
Uncleaned rye grains	---	---	~407	---
Wheat	~54	~204	~610	336
Barley	~4.5	~610	~2239	246
Buckwheat	~4.5	~204	~2442	248
Oat	~432	---	~4884	---
Beans	~108	---	---	---
Peas	---	~68	~610	132
Millet	~18	~3	~18	874
Flax seeds	~9	---	---	---
Poppy seed	---	~3	---	---
Cannabis seed	---	~3	---	---

In the first half of the 17th century, millet was practically eliminated from the fields of Lithuanian manors, with rye, oats, wheat, and barley dominating. For example, in 1629, the Radziwill family's Papilys manor fields were sown with ~49247 L of winter rye, ~5719 L of summer rye, ~3693 L of wheat, ~1231 L of spelta wheat, ~4902 L of barley, ~3256 L of peas, ~844 L of buckwheat, ~72,862 L of oat, ~2442 L of flax seeds, and ~204 L of cannabis seeds.

Despite the fact that millet was not widely cultivated on manorial fields in the 16th century, this cereal was mentioned in the Third Statute of Lithuania in 1588 (probably by inertia). It is interesting to note that the Statute refers to cereals in two ways: in the calculation of the value of fields sown with cereals and in the valuation of cereals already harvested [62]. A comparison of the values of the different cereals described in the Statute is presented in Table 4, where millet is priced quite low in comparison to other crops (Table 4).

6. A Hypothetical Explanation of Millet Abandonment

Examining the circumstances that led to the abandonment of millet cultivation in Lithuania between the second half of the 15th and the 17th century, we can distinguish two factors: (i) climate change (the Little Ice Age), and (ii) agricultural reforms in Lithuania at the time (the Volok Reform). Due to climate change in the region, the length of the growing season became shorter, while during the Volok Reform, which started in 1547, the choice of crops became highly regulated (Table 5).

A warm medieval period that was identified for Lithuania between AD 1080 and 1350 was followed by the Little Ice Age [74]. The term Little Ice Age refers to the period between AD 1300/1500 and AD 1850, when global average temperatures declined compared to the previous medieval warming period [75–77]. Temperature and precipitation during the Little Ice Age varied significantly around the world. For example, in Scandinavia "... cooling was clearly seen approximately between AD 1560–1720 while low temperatures were also prevailing c. AD 1350 and c. AD 1900 [78]. The total reconstructed decadal temperature variability of the last 12 decades is about 2.5 °C, with a centennial variability of as much as 1.5 °C..." [78]. In Central Europe "... a very clear, albeit somewhat variable, Little Ice Age is seen from c. AD 1250 until the mid-19th century with a maximum cooling in the 17th century..." [78]. Dry and cold climatic conditions predominated in Germany and high-latitude Sweden during the early Little Ice Age (1470–1610 CE). In

Lithuania, after AD 1350, vegetation history corresponds with a gradual reduction in signs of human activity and the expansion of woodlands due to climatic deterioration [74,79]. During the second half of the Little Ice Age (from AD 1610 to 1750) the climatic conditions probably became wetter for Germany [80], while in northwest Poland a drop in water levels was recorded over the period AD 1640–1720, indicating an arid and cold phase [81]. According to Eastern European May–June temperature reconstruction from tree rings, falls in temperatures were recorded between the middle of the 14th and the middle of the 17th centuries, with temperatures being −0.7–2.7 °C cooler than in 1961–1990 [82–85]. The cooling episodes had a significant impact on the length of the crop growing season. It has been estimated that a one-degree decline in temperature in Europe will shorten the growing season by three to four weeks [86–88]. The shortening of the growing season in Lithuania is recorded through changes in naturally growing tree species over the last millennium [89].

Table 5. The values of the different cereals described in the Third Statute of Lithuania (values in the groschen of the Grand Duchy of Lithuania).

Cereal	Value in Groschen of 1 Morgen of Land Sown with Cereals	Value in Groschen of 1 Stook of Cereals
Winter rye	180–300	20
Summer rye	180	20
Summer wheat	360	20
Spelt wheat	---	10
Barley	360	10
Buckwheat	300	8
Oat	240	8
Beans	---	8
Peas	360	10
Lentils	240	6
Millet	240	8

The shorter growing season changed the technology of millet cultivation in Lithuania. Syrennius (1613) [71] has documented a transition from older to newer technologies applied to the cultivation of millet. He mentions that at his time "…millet is sown in spring, on April or March. They ripen in the fourth or fifth month…". But also "…they [millet] are sometimes sown twice a year: in spring and early September…" [71]. We can presume that these two-harvest millet cultivation technologies and practices were established in the earlier (medieval warming) period that occurred in Lithuania between 1080 and 1350 AD [74]. This technology allowed millet to be sown twice a year, one after the other, or as a second crop to be sown after the harvest of another summer crop (barley or oats). In this way, a much higher cereal yield was obtained. However, the cooling of the climate (the Little Ice Age) made it impossible to apply this technology and drove the shift to single-yield millet cultivation. Syrennius writes about a rather early sowing time for millet (March–April). However, in the second half of the 17th and the 18th centuries, the sowing time was much later (May–June). A new agrotechnology means that: "…sowing of millet and buckwheat is in May, on the days of the Cross (before Ascension Day)…" or "…sowing of cannabis, flax and millet is on St Urban day (May 25)…" [90]. The same late sowing technology is repeated in the descriptions of millet cultivation up to the 20th century. E.g. millet "…sowing time is mid-May when there is no risk of frost…" [91]; "…is sown late in the spring, because it is not resistant to the frost…" [72].

Between the 11th and 18th centuries, the cultivation of millet decreased in Lithuania and in neighboring regions of the same latitude, e.g., in the Polack region of Belarus (the territory of the GDL in medieval and early modern times) in the 11th–18th centuries AD [92].

Stable isotope results on human bone collagen from Lithuania and other neighboring regions indicate both human and animal diets based on C3 terrestrial resources, while no evident contribution of marine fish or C4 plants (millet) was identified [92–97]. Analysis of the medieval diet in north-central Poland showed the removal of millet as a menu item during the medieval period [98].

The second possible factor was agricultural reform (the Volok Reform), which began in AD 1547 at the Grand Duke's manors and continued until the last quarter of the 16th century. The reasons for the Volok Reform were related to changes in the political and economic circumstances within Lithuania during the 16th century. The need to defend Lithuania against the Tatars and the Muscovites required more revenue from the state treasury. The lack of revenue also highlighted other problems: the inefficient administration of the Grand Duke's landholdings, the variety of taxes, and inefficient tax collection and accounting. The state was forced to look for additional sources of revenue. The focus of the debate shifted to improving the administration of the ruler's landholdings, which were generating the most revenue. On the other hand, the growing population of Western European cities and the reduction in cereal harvests due to climate change (Little Ice Age) in European countries created a large market for food exports from Lithuania. The main aim of the Volok Reform was to increase productivity and establish the market orientation of agriculture. The most important principles of the Volok Reform were developed on the lands ruled by the Grand Duchess of Lithuania, Bona Sforza (AD 1494–1557). The reforms started in AD 1547 on the basis of the "Regulations for the Administrators of Castles and Manors". The Reform Law was issued by the Grand Duke of Lithuania Sigismund Augustus (AD 1520–1572) in AD 1557. As part of the reforms, land owned by estates and peasants was measured in Voloks, and obligations were based on the amount of land owned. The land was joined into topographically homogeneous areas. The peasants were settled in street villages, and their land was divided into three parts. In this way, three-field farming became the generally accepted land management system. Other measures to increase agricultural productivity (crop rotation, manure fertilization, and legume sowing) were introduced. Recognizing the benefits of the reform, the nobility, the Church, and the landowning gentry implemented its principles on their own estates [99].

The Volok Reform enabled a surplus of grain in Lithuania and increased grain exports to Western Europe. This led to increased cultivation of cereals in demand at a higher market value (wheat and rye for bread, barley for beer, and oats for horse feeding). Furthermore, the Western European nations that received grain imports from the eastern Baltic region perceived millet as a typical "eastern" cereal and chose to import more familiar crops for consumption. For example, giving millet to the 17th-century Venetians could provoke riots [100]. Syrennius mentions that "... millet is not much edible, but those who are habituated to it from their childhood—like us Poles, French, Germans, Lithuanians, Ruthenians and Podolians—eat it easily..." [71]. The Third Statute of Lithuania suggests (Table 4) that the market value of millet was low compared to other cereals. As its export to other countries was not profitable, its cultivation shrank, and other cereals pushed millet out of the majority of cultivated fields. The royal demesnes and peasant farms of 16th century Poland were heavily focused on producing grain for export; thus, foreign demand for Polish grain inevitably shaped the supply, prices, and structure of grain production, resulting in increased cultivation of wheat, barley, and rye [101].

Although millet cultivation was pushed out of royal estates, some historical documents from Poland do mention local small-scale cultivation among peasants [101]. From the second half of the 17th to the 19th century, however, millet, if mentioned in written sources at all, was more often an item to be traded than cultivated.

References to gastronomical uses of millet in Lithuania are rare and only sporadically documented in written sources until the 20th century. This indicates that other cereal crops were preferred to millet. As it has been argued, the decrease in its use was driven by multiple factors that included climate change, the Volok Reform, and culinary choice.

7. Conclusions

Millet was introduced in Lithuania around 1100 cal BCE, as seen from direct radiocarbon dating of millet grains. Unlike other cereals, millet was uninterruptedly used among the major staple foods almost until the 15th century. It has been recovered from various sites across Lithuania covering a broad chronological period, with the highest ubiquity and abundance of millet remains found at the sites dated to the first half of the 1st millennium BCE and the 13th–14th centuries AD. In the transition from BCE to AD (for the early Iron Age between 300 and 0 BCE) and during the first half of the 1st millennium AD, millet consumption was sporadic and was not identified in all archaeobotanically analyzed sites. Yet, systematic archaeobotanical research at archaeobotanical sites in Lithuania is relatively new, and future extensive studies might improve our understanding of the intensity of millet use across time in relation to other crops.

There is an evident decline in millet use in Lithuania from the 15th through to the beginning of the 18th centuries as seen from both historical and archaeobotanical sources. In addition, the overview of stable isotope values of human and animal bone collagen does not show any evidence of millet consumption in the diet of the local population in Lithuania. In this paper, we suggest that climatic factors and the implementation of agricultural reforms, which tightly regulated what cultigens had to be sown in response to export demand, could have played an important role in the decrease in millet use in Lithuania. Yet further research must be conducted to link high-resolution climatic data with millet cultivation, along with understanding millet use in relation to other cereal crops as culinary preferences rather than climate or agrarian reforms alone could have led to the decrease in millet cultivation during the historical period in Lithuania.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/agronomy13082171/s1. Supplementary Material S1: SOM1_LTmillets_calibrated dates across time. Supplementary Material S2: SOM2_The database of all radiocarbon dates from locations with broomcorn millet discoveries and the list of coordinates for the Figure 1.

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