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LIGHT STABLE ISOTOPE ANALYSIS OF DIET IN CORDED WARE CULTURE COMMUNITIES: ŚWIĘTE, JAROSŁAW DISTRICT, SOUTH-EASTERN POLAND

ABSTRACT

The presented study was based on isotopic analysis of $\delta^{13}C$ and $\delta^{15}N$ in human bone collagen samples from graves of the Corded Ware culture in Święte, south-east Poland. Isotopic values demonstrate a relatively narrow variation, ranging from -20.4‰ to -19.8‰ and 10.6‰ to 12.0‰ for $\delta^{13}C$ and $\delta^{15}N$ values, respectively. The diet was likely C3 plant-based with a substantial animal protein component, including predominantly terrestrial and possibly riverine resources.

Key words: stable isotope analysis, diet, Corded Ware culture

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INTRODUCTION

Archaeological science utilises the analysis of stable light isotopes of human and faunal material to provide insights into past populations [Pate 1997; Ambrose, Krigbaum 2003; Makarewicz, Sealy 2015]. Isotopic signals, expressed in parts per mille [‰], support palaeodietary reconstruction. Carbon ($\delta^{13}C$) potentially allows differentiation between terrestrial and marine resources [Carvalho, Petchey 2013], as well as plant groups consumed (C3 and C4 plants) [Lee-Thorp 2008]. The $\delta^{13}C$ values of C3 plants are typically between -34‰ and -22‰ according to O'Leary [1988] or -35‰ to 20‰ according to Katzenberg [2000], while the C4 plants usually display values from -14‰ to -9‰ [Katzenberg 2000]. Nitrogen ($\delta^{15}N$) mainly provides evidence for trophic level in the food chain, and may inform on environmental stress [*e.g.* Bocherens, Drucker 2003].

Human and animal tissues display values higher than the consumed diet due to the diet-tissue offset [e.g. Finucane 2007]. In herbivores, $\delta^{13}C$ exceeds the values of the consumed plant by approximately 5‰, while in carnivores the values will typically increase by 1‰ at each trophic level [van der Merwe, Vogel 1978; van Klinken *et al.* 2002]. The heavier isotope ^{15}N is accumulated, causing an increase in the $\delta^{15}N$ values by 3-4‰ with each trophic level [DeNiro, Epstein 1981; DeNiro 1985; Lee-Thorpe *et al.* 1989]. Human collagen values of $\delta^{13}C$ and $\delta^{15}N$ are enriched by about 5‰ and 3‰ respectively, compared to the consumed diet. Since the isotopic signal of the local flora is often influenced by multiple environmental factors, it is essential that a local baseline be established to facilitate a robust interpretation of the isotopic data for past populations [Ambrose 1993].

This study presents the carbon and nitrogen isotopic analysis and long-term diet interpretation for the Corded Ware culture (CWC) in the Lower San Valley in the south-east Poland [Dobrakowska, Włodarczak 2018; Janczewski *et al.* 2018; Olszewski, Włodarczak 2018]. They are then compared to contemporary individuals from the neighbouring region of the Rzeszów Foothills (Fig. 1).

1. MATERIAL AND METHODS

Human bone was sampled from 12 individuals excavated at three sites located in Święte (sites 11, 15 and 20) and subjected to the analysis of $\delta^{13}C$ and $\delta^{15}N$. The bone collagen extracted at the Poznań Radiocarbon Laboratory was subjected to $\delta^{13}C$ and $\delta^{15}N$ analysis at the Isotope Dating and Environment Research Laboratory, Institute of Geological Sciences of the Polish Academy of Sciences, Warsaw [Goslar *et al.* 2017]. The material was analysed using single samples, combusted

F i g . 1 . Location of Final Eneolithic and Early Bronze Age sites analysed in the paper: 1 – Święte, site 11, 2 – Święte, site 15, 3 – Święte, site 20, 4 – Dobkowice, site 37 and 39, 5 – Chłopice, site 11, 6 – Szczytna, site 5, 7 – Szczytna, site 6, 8 – Mirocin, site 24, 9 – Mirocin, site 27

using a Thermo Flash EA 1112HT elemental analyser connected to a Thermo Delta V Advantage isotope ratio mass spectrometer in a Continuous Flow system. The international standards were USGS 40, USGS 41 and IAEA 600, with the analytical error for $\delta^{13}C$ and $\delta^{15}N$ calculated at 0.33‰ and 0.43‰ respectively.

The local baseline was established using cattle (*Bos taurus*) and pig (*Sus domesticus*) sample values from the Early Bronze Age Mierzanowice culture, sites number 37 and 39 in Dobkowice near Jarosław in the same region of south-east Poland [Werens *et al.* 2018]. The human results were then compared with published data from the Final Eneolithic and the Early Bronze Age sites in the Rzeszów Foothills in Poland [Szczepanek *et al.* 2018] and the Early Bronze Age Yampil Barrow Complex (YBC) sites in Ukraine [Goslar *et al.* 2017].

2. RESULTS AND DISCUSSION

All human and animal bone collagen samples had C:N values within the accepted ranges of 2.9-3.6 [DeNiro 1985] and 3.1-3.5 [van Klinken 1999], indicating good collagen preservation. Further quality control measures included %C and %N, which were within tolerance [Ambrose 1990]. The full results are presented in Table 1 and Figure 2.

The majority of the human samples from Święte displayed $\delta^{13}C$ values within a narrow range of -20.4‰ to -19.8‰, the average being -20.0‰ (SD=0.1). The $\delta^{15}N$ values, ranging from 10.6‰ to 12.0‰, displayed larger dispersion, with an average of 11.4‰ (SD=0.5). It is notable that the $\delta^{15}N$ values of all of the identified males were among the highest measured values from Święte, and form a distinctive cluster. The size of the dataset was not sufficient to investigate dietary differences between sexes, given the presence of only 2 identified females and 6 males, while the sex of the remaining 4 individuals (33.3% of the sample) was impossible to assess. Having noted the limitations posed by a small sample size, the dataset was analysed for differences between the males and all other individuals, with females and unidentified individuals combined. The Kolmogorov-Smirnov test revealed that data was distributed normally and an independent sample t-test was performed with a 95% confidence interval. A comparison of the mean isotopic values of males ($\delta^{13}C$=-20.1‰, SD=0.1; $\delta^{15}N$=11.7‰, SD=0.2) and all other individuals sampled from the sites in Święte ($\delta^{13}C$= -19.9‰, SD=0.1; $\delta^{15}N$=11.2‰, SD=0.5) revealed a difference in $\delta^{13}C$ between the groups (p=0.003), but no statistically significant difference in $\delta^{15}N$ values (p=0.088). The interpretation of the results based on a relatively small sample requires caution, yet the group of males from Święte appears to have had a distinctly different isotopic signal, at least in regard to the $\delta^{13}C$ values. That said, the group of 'all other individuals' included women, as well as 2 juveniles and 4 people of unidentified sex, which renders the robust assessment of dietary differences between males and females impossible.

The baseline was established using faunal data (*Bos taurus, Sus domesticus*) from sites in Dobkowice within the same Subcarpathian region, where the animals demonstrate levels of $\delta^{13}C$ and $\delta^{15}N$ lower than the average human results by 1.4‰ and 4.2‰ respectively. Assuming the animals within the region had similar isotopic composition, the results indicate that the sampled individuals from Święte had a C3 plant-based diet with a substantial contribution from animal protein, which could include both meat and dairy.

The above-mentioned group of men whose $\delta^{13}C$ values differed significantly from the remaining individuals, subsisted on a diet that was depleted in $\delta^{13}C$ and enriched in $\delta^{15}N$. One food group that may have contributed to this shift is freshwater resources [Katzenberg 1989]. The modern distance between the sites and the

Table 1

The results of radiocarbon dating and stable isotope analysis of human collagen

No.	Site	Feature No.	Sample No.	Date BP	Age	Sex	$\delta^{13}C$ [‰]	$\delta^{15}N$ [‰]	%C	%N	C:N
1	Święte 11	876	Poz-90875	3890 ± 35	40-50	M	-20.2	11.9	40.8	14.6	3.25
2	Święte 11	1134	Poz-90877	4020 ± 30	25-30	M	-20.2	11.5	50.1	18.3	3.20
3	Święte 11	1149A	Poz-90884	3925 ± 35	50-60	M	-20.0	11.6	39.8	14.2	3.27
4	Święte 11	1290D	Poz-90876	3875 ± 35	20-30	M	-20.0	12.0	43.3	15.7	3.23
5	Święte 15	173	Poz-90779	3935 ± 30	30-40	F	-19.9	10.6	47.8	17.3	3.22
6	Święte 15	407A	Poz-90882	3955 ± 35	20-50	?	19.8	11.2	51.5	18.9	3.17
7	Święte 15	408A	Poz-90780	3890 ± 35	30-40	F	-19.9	11.2	49.6	18.4	3.16
8	Święte 15	409	Poz-90781	3990 ± 30	20-50	?	-19.8	10.7	46.5	16.8	3.23
9	Święte 15	427	Poz-90874	3890 ± 35	6-7	?	-20.4	11.1	40.8	14.7	3.23
10	Święte 15	431	Poz-90782	4020 ± 35	20-50	?	-19.9	11.7	43.1	15.5	3.24
11	Święte 20	40A	Poz-90777	3950 ± 35	6-7	M	-20.0	11.9	49.1	18.2	3.15
12	Święte 20	43/1	Poz-90778	3950 ± 35	40-45	M	-20.1	11.5	46.0	16.8	3.20

River San is *c*. 700 m and it is possible that riverine fish was one of the sources of protein. The identified men may have consumed larger quantities of fish than the others, whose diet was presumably more C3 plant-based.

3. DIET OF THE CORDED WARE CULTURE IN THE SUBCARPATHIAN REGION, SE POLAND

The isotopic data for the sites in Święte was compared with other CWC sites from the neighbouring Rzeszów Foothills [Szczepanek *et al.* 2018]. The results

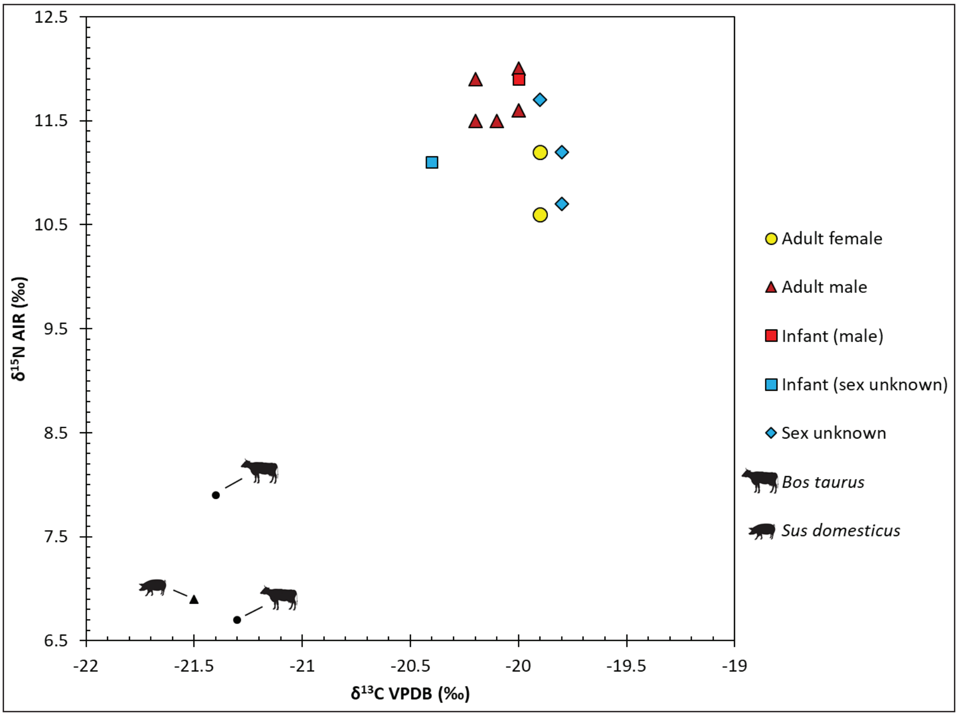


Fig. 2. $\delta^{13}C$ and $\delta^{15}N$ values in human samples from Święte and animal samples from Dobkowice (Rzeszów Foothills)

show a clustered distribution, with a couple of outliers: two individuals from Mirocin (Fig. 3).

The highest $\delta^{13}C$ and $\delta^{15}N$ values displayed by a 3 to 4-year-old child from Mirocin are higher than the mean Mirocin $\delta^{13}C$ and $\delta^{15}N$ values by 0.9‰ and 2.9‰ respectively, while the difference between the child and all CWC sites in the region was 0.7‰ and 2.1‰ for $\delta^{13}C$ and $\delta^{15}N$ respectively. This corresponds with the values typically attributed to a single trophic level shift [DeNiro, Epstein 1981], often related to breastfeeding practices [Larsen 2015:324]. It is probable that at the age of 3 or 4 the child was either not weaned or that the isotopic body pool had not yet decreased after weaning was completed to then reflect the altered nutritional intake.

The adult male from Mirocin with the lowest isotopic values in the discussed CWC sites had $\delta^{13}C$ and $\delta^{15}N$ values lowered by 0.4‰ and 1.9‰ respectively in comparison to the average results in adults from these sites. This indicates that the man probably had a more plant-based diet [Szczepanek *et al.* 2018].

Fig. 3 takes into account the results of strontium isotope analysis ($^{87}Sr/^{86}Sr$), which facilitates provenance estimation [Szczepanek *et al.* 2018; Belka *et al.*

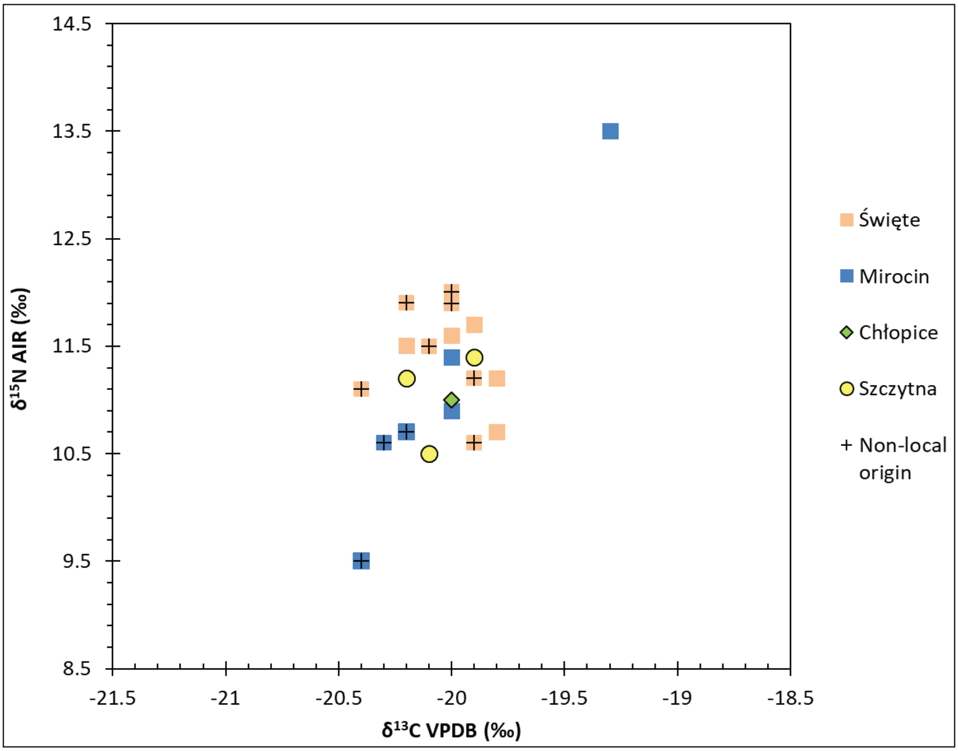


Fig. 3. Plot of $\delta^{13}C$ and $\delta^{15}N$ values for CWC humans from the Subcarpathian region

2018]. Amongst the sample from the Subcarpathian region, 10 individuals are of non-local origin.

The statistical analysis of the data from the Subcarpathian region provides strong evidence ($p = 0.013$) of variance in $\delta^{15}N$ levels between Święte (mean value 11.4‰, SD = 0.5) and other sites in the region (mean value = 10.8, SD = 0.6). No difference in $\delta^{13}C$ was identified (Fig. 3).

The next step in the analysis of data was the investigation of sex-related differences in the Subcarpathian region. Among the adult individuals, a grouping of males is standing out (Fig. 4). Given the non-normal distribution of the carbon and nitrogen data, the Mann-Whitney test was performed, concluding that the $\delta^{15}N$ values in males are significantly higher than in females from the analysed area ($p=0.045$). There is no observed distinction in $\delta^{13}C$ values.

Constraining this analysis was the inability to sex 3 of the adult individuals, which to a smaller sample may have unfairly biased the results. Nevertheless, the individuals sampled from the Subcarpathian region sites, identifying as males, are likely to have subsisted on a slightly different diet than the collective 'other'.

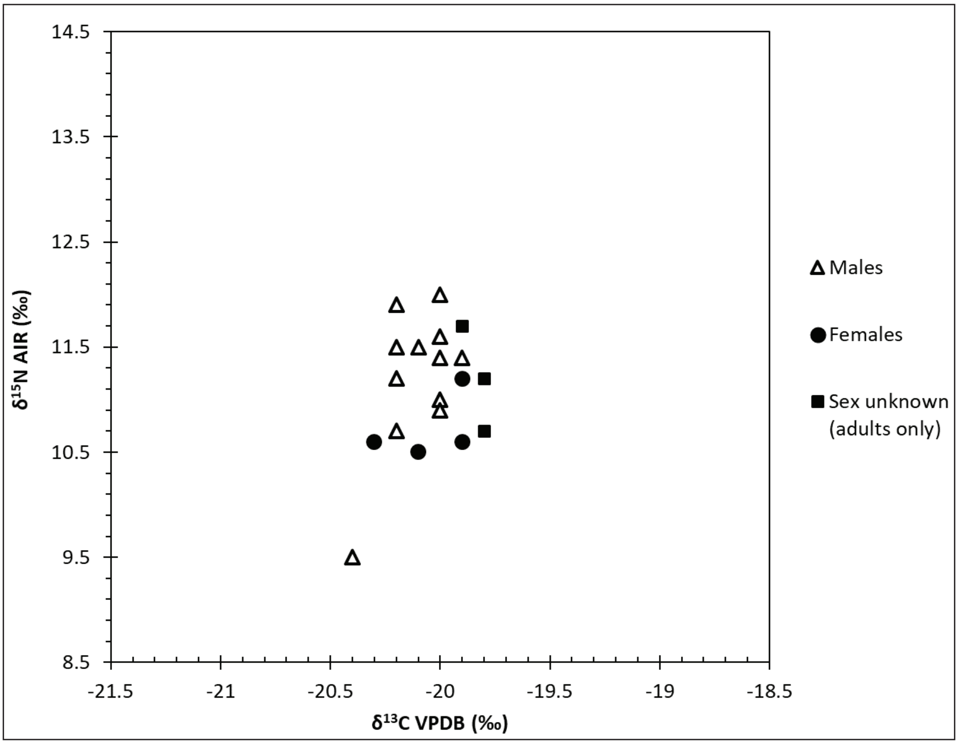


Fig. 4. Plot of $\delta^{13}C$ and $\delta^{15}N$ values for CWC adult individuals from the Subcarpathian region

It is difficult to provide a palaeodietary interpretation of the results and explanation for the dietary differences in the two analytical comparisons presented above: ‘Sites in Święte vs. sites in the Rzeszów Foothills’, and ‘Males vs. Females’. In both couplings, only the differences in $\delta^{15}N$ levels could be confirmed as statistically significant. The elevated $\delta^{15}N$ values, with only a slight decrease in $\delta^{13}C$, might be interpreted as a possible evidence for riverine fish consumption. The $\delta^{13}C$ values of freshwater fish are often lower than in terrestrial animals, while the $\delta^{15}N$ levels tend to be fairly high due to the length of the trophic chain in riverine and lake ecosystems [Hesslein 1991; Katzenberg 1989]. However, it is not possible to confirm this hypothesis without establishing a local baseline using contemporary faunal material, ideally from the same sites. There were no fish bones recovered from the sites in Święte, although absence of evidence is not evidence of absence; particularly so on prehistoric sites where very small animal bones may not have survived.

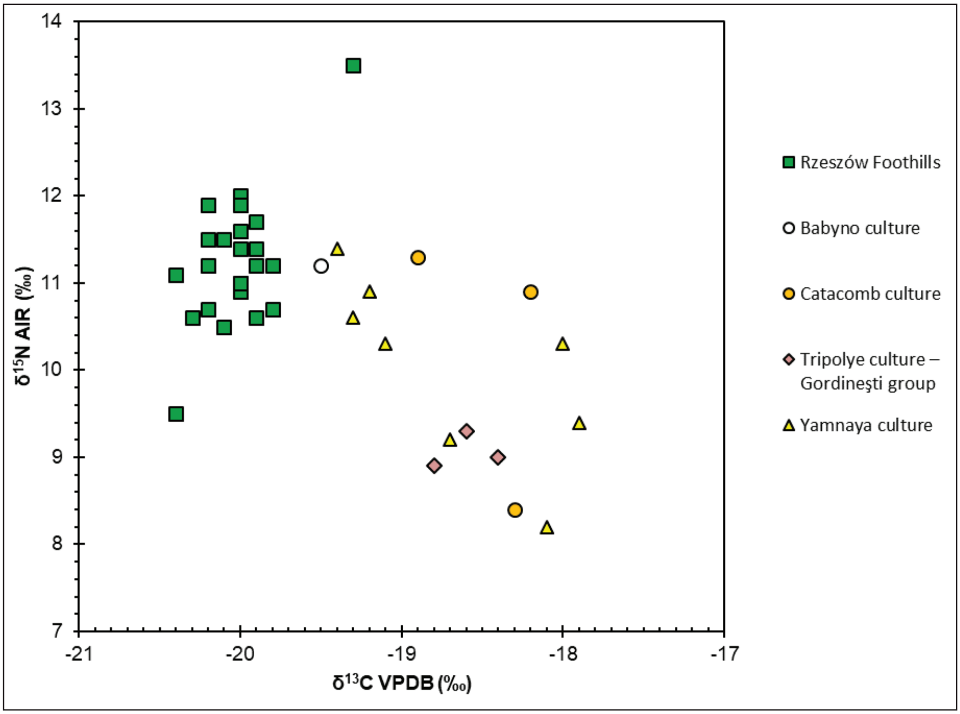
4. DIET OF THE CORDED WARE CULTURE COMMUNITIES FROM THE RZESZÓW FOOTHILLS COMPARED TO THE FINAL ENEOLITHIC AND EARLY BRONZE AGE SOCIETIES IN MODERN-DAY UKRAINE

Grave goods from the CWC sites in the Lower San Valley/Rzeszów Foothills indicate influences from Final Eneolithic Ukraine [Kośko, Włodarczak 2018]. One notable example comes from Święte 11, where a round-bottom vessel was recovered from the layer immediately above grave 1149A. Its style is believed to derive from the Early Bronze Age Pontic cultures [Kośko *et al.* 2018]. Given the possible cultural association between the sites in the Subcarpathian region and modern-day Ukraine, the isotopic results from the analysed area were compared with the $\delta^{13}C$ and $\delta^{15}N$ values from the Late Eneolithic Tripolye culture (Gordineşti group) and three Early Bronze cultures: the Yamnaya culture, the Catacombnaya culture and the Babyno culture. These cultures altogether were grouped to form the Yampil Barrow Complex (YBC; Fig. 5). The original analysis of the YBC material had been conducted in the course of the *Yampil Investigation Programme* in 2011-2016 [Goslar *et al.* 2014, 2015, 2017].

The comparison of the individuals sampled at the CWC sites in the Subcarpathian region and the people from YBC sites in modern-day Ukraine reveals the most striking divergence so far (Fig. 5). Independent sample t-tests provided very strong evidence for statistical differences in both $\delta^{13}C$ and $\delta^{15}N$ values ($p<0.001$). In the CWC individuals, the mean $\delta^{13}C$ was -20.0‰ (SD=0.2), while the YBC measured -18.7‰ (SD=0.5). The mean $\delta^{15}N$ levels at the CWC and YBC sites were 11.2‰ (SD=0.7) and 9.9‰ (SD=1.1) respectively. The CWC data is much more clustered than the YBC results, indicating smaller intrapopulational variation in diet in the Subcarpathian region.

It is very probable that the diet of the sampled individuals involved different subsistence strategies, although environmental factors cannot be excluded. Interpretation of the results is limited by the scarcity of environmental data, particularly faunal remains that could help establish the local baseline. While in the Rzeszów Foothills there were three animal samples analysed from Dobkowice, the YBC dataset did not include any faunal remains.

There are a few possible explanations for the isotopic differences between the two groups, the most plausible hypothesis being an increased share of C4 plants in the diet of the YBC individuals compared to the Subcarpathian region sample. Millet (*Panicum mileaceum*) was probably included in the diet of the forest-steppe communities as early as 5000 BC, having spread into the Eurasian steppe from China [Murray, Schoeninger 1988; Svyatko *et al.* 2013]. Although some sources suggest millet only became a staple crop in the Northern Pontic area of modern Ukraine in the Late Eneolithic and Early Bronze Age *c.* 3300-2800 BC [Goslar



F i g . 5 . Plot of δ^{13}C and δ^{15}N values for CWC humans from the Subcarpathian region and the Late Eneolithic and the Early Bronze Age groups from Ukraine (Yampil region)

et al. 2018], the C4 signals are not very strong in human isotopic values before 800 AD. Until this point millet was mainly used as animal feed [Murray, Schoeninger 1988; Bonsall *et al.* 2004]. Notably, at the discussed YBC sites there is archaeobotanical evidence for millet gathered from the funerary contexts [Goslar *et al.* 2018], which is further supported by crop impressions identified on Yampil pottery on the Lower Dniester steppe, believed to be of millet [Goslar *et al.* 2018, *after* Kuzminova 1990: 261].

The YBC human isotopic values of δ^{13}C, ranging from -19.5‰ to -17.9‰, are relatively low for a C4 or a mixed C3 and C4 plant diet. The δ^{13}C values of C3 plants are between -35‰ and -20‰, and from -14‰ to -9‰ for C4 plants [Katzenberg 2000]. However, there seems to be a C4 component in the diet, as the YBC results are higher than in the Subcarpathian region sample that represents a typical moderate climate C3-based diet with an animal protein contribution. The authors of the initial study suggested that the δ^{13}C values may have been lowered as a result of consuming animal protein derived from terrestrial animals which subsisted on a C3 plant-based diet, as well as freshwater fish [Goslar *et al.* 2018]. This explanation is not convincing for all individuals, as the fairly low δ^{15}N values (mean=9.9, SD=1.1) do not support the riverine fish consumption argument. Moreover, as already mentioned, previous research suggests that millet probably was not consumed in Europe by humans until the first millennium AD, but instead was fed to the animals. If millet appeared in the trophic chain of the individuals from the YBC sites, it is plausible that the C4 signal was transferred to humans from the animals which consumed some millet in the first place. In this way it may have caused a slight increase in the $\delta^{13}C$ values and a statistically significant difference between YBC and CWC individuals. As discussed above, the individuals from the Subcarpathian region were in fact more probable to have consumed riverine fish, as such intake would justify their elevated $\delta^{15}N$ and lower $\delta^{13}C$ values.

In addition to the dietary regimes, it is possible that environmental and climatic factors contributed to the differences between the two compared groups. The distance between the Lower San Valley/Rzeszów Foothills in Poland and Yampil in Ukraine is about 500 km, but the two regions have their own distinct climatic conditions. Unlike the Subcarpathian region, the analysed YBC has a temperate continental climate with steppe vegetation [Bednarek, Jankowski 2014]. Plants growing in a forest environment often exhibit lower $\delta^{13}C$ values than of those growing in open spaces [Drucker *et al.* 2008, Reitsema *et al.* 2013]. Such environmental variation may have contributed to the differences in human isotopic values from both regions, however, further assessment requires local baseline data.

5. CONCLUSIONS

Isotopic analysis of $\delta^{13}C$ and $\delta^{15}N$ in bone collagen samples from the CWC sites in the Subcarpathian region, south-east Poland, enabled a long-term palaeodietary reconstruction, which indicated a moderate climate terrestrial diet based on C3 plants and animal protein, with possible riverine resources consumptions.

The analysis concluded that the identified male individuals from Święte displayed $\delta^{13}C$ values significantly lower than the remaining individuals, but no statistically significant difference in the $\delta^{15}N$ values, although with p=0.088, this sample was on the borderline of statistical significance. The distinct isotopic values in males from Święte may have been caused by a relatively larger consumption of freshwater fish.

The data from Święte was then compared to isotopic results from other CWC sites in the region of the Rzeszów Foothills. With the average of 11.4‰ (SD=0.5), the $\delta^{15}N$ values are higher than at other sites in the region. A similar difference in $\delta^{15}N$ values was noted between males and females, with the male diet possibly having a more significant riverine component than the female diet.

The strongest differences were noted between the CWC sites in the Subcarpathian region and the YBC sites in modern-day Ukraine. The individuals from the Late Eneolithic and Early Bronze Age YBC sites had higher $\delta^{13}C$ values, which are interpreted as a C4 plant signal derived from animals consuming some amount of millet. However, environmental data to confirm it is scarce, and the local baseline has not be established. By comparison, the individuals from the Subcarpathian region seem very unlikely to have consumed millet or animals that were fed on C4 plants. It is also possible that environmental factors contributed to the differences in $\delta^{13}C$ values [van Klinken *et al.* 2002]. The higher $\delta^{15}N$ values may have been caused by consumption of riverine fish from the River San.

It is most desirable to interpret the stable isotope analysis results in the context of a local baseline, established using contemporary faunal assemblages and archaeobotanical data, ideally from the same sites. For the dietary reconstruction of the individuals from Święte, a faunal dataset from the Early Bronze Age Mierzanowice culture sites in Dobkowice nearby was used. It did not include any fish bone. Recommendations for future research include identifying suitable material that may allow confirmation that the riverine fish constituted a significant contribution to the diet of the individuals from Święte and sites in the Rzeszów Foothills.

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REFERENCES

Ambrose S.H.

1990 Preparation and characterization of bone and tooth collagen for isotopic analysis. *Journal of Archaeological Science* 17: 431-451.

1993 Isotopic analysis of paleodiets: methodological and interpretative considerations. In: M.K. Sandford (Eds) *Investigations of Ancient Human Tissue Chemical Analyses in Anthropology,* 59-130. Langhorne.

Ambrose S. H., Krigbaum J.

2003 Bone chemistry and bioarchaeology. *Journal of Anthropological Archaeology* 22: 193-199.

Bednarek R., Jankowski M.

2014 Charakterystyka gleboznawcza materiału budującego nasyp kurhanu 1 w Pidlisiwce. In: A. Kośko, M. Potupczyk, S. Razumow (Eds) *Naddniestrzańskie kompleksy cmentarzysk kurhanowych społeczności z II i z pierwszej połowy II tysiąclecia przed Chr. w okolicach Jampola, obwód winnicki. Archaeologia Bimaris – Monografie* 6, 275-280. Poznań.

Belka Z., Dopieralska J., Szczepanek A., Jarosz P.

2018 Human mobility in the Final Eneolithic population of Święte, Jarosław District, south-eastern Poland: evidence from strontium isotope data. *Baltic-Pontic Studies* 23: 246-258.

Bocherens H., Drucker D.

2003 Trophic level isotopic enrichment of carbon and nitrogen in bone collagen: case studies from recent and ancient terrestrial ecosystems. *International Journal of Osteoarchaeology* 13: 46-53.

Bonsall C., Cook G.T., Hedges R.E.M.

2004 Radiocarbon and stable isotope evidence of dietary change from the Mesolithic to the Middle Ages in the Iron Gates: new results from Lepenski Vir. *Radiocarbon* 46: 483-495.

Carvalho A. F., Petchey F.

2013 Stable isotope evidence of Neolithic palaeodiets in the coastal regions of Southern Portugal. *The Journal of Island and Coastal Archaeology* 8(3): 361-383.

DeNiro M. J.

1985 Postmortem preservation and alteration of in vivo bone collagen isotope ratios in relation to paleodietary reconstruction. *Nature* 317: 806-809.

DeNiro M. J., Epstein S.
1981 Influence of diet on the distribution of nitrogen isotopes in animals. *Geochimica et Cosmochimica Acta* 45: 341-351.

Dobrakowska T., Włodarczak P.
2018 Święte 20: graves of the Corded Ware culture. *Baltic-Pontic Studies* 23: 140-162.

Drucker D.G., Bridault A., Hobson K.A., Szuma E., Bocherens H.
2008 Can carbon-13 in large herbivores reflect the canopy effect in temperate and boreal ecosystems? Evidence from modern and ancient ungulates. *Paleogeography, Palaeoclimatology, Palaeoecology* 266: 69-82.

Finucane C.B.
2007 Mummies, maize, and manure: multi-tissue stable isotope analysis of late Prehistoric human remains from the Ayacucho valley, Peru. *Journal of Archaeological Science* 34: 2115-2124.

Goslar T., Kośko A., Razumow S.
2014 Identyfikacja kulturowo-chronologiczna cmentarzysk „wczesnobrązowych" na stanowisku Pidlisiwka 1. In: A. Kośko, M. Potupczyk, S. Razumow (Eds) *Naddniestrzańskie kompleksy cmentarzysk kurhanowych społeczności z II i z pierwszej połowy II tysiąclecia przed Chr. w okolicach Jampola, obwód winnicki. Archaeologia Bimaris – Monografie* 6, 305-312. Poznań.

Goslar T., Klochko V. I., Kośko A., Włodarczak P., Żurkiewicz D.
2015 Chronometry of late Eneolithic and Early Bronze cultures in the middle Dniester area: investigations of the Yampil barrow complex. *Baltic-Pontic Studies* 20: 256-291.

Goslar T., Jankowski M., Kośko A., Lityńska-Zając M., Włodarczak P., Żurkiewicz D.
2017 Builders and users of ritual centres, Yampil Barrow Complex: Studies of diet based on stable carbon and nitrogen isotope composition. *Baltic-Pontic Studies* 22: 91-125.

Hesslein R.H., Capet M.J., Fox D.E., Hallard K.A.
1991 Stable isotopes of sulphur, carbon, and nitrogen as indicators of trophic level and fish migration in the lower Mackenzie River Basin, Canada. *Canadian Journal of Fisheries and Aquatic Science* 48: 2258-2265.

Janczewski P., Kraus P., Włodarczak P.
2018 Święte 15: cemetery of the Corded Ware culture. *Baltic-Pontic Studies* 23: 93-139.

Katzenberg M.A.
1989 Stable isotope analysis of archaeological faunal remains from Southern Ontario. *Journal of Archaeological Science* 16: 319-329.

Katzenberg A.M.
2000 Stable isotope analysis: a tool for studying past diet, demography, and life history. In: A.M. Katzenberg, S.R. Saunders (Eds) *Biological Anthropology of the Human Skeleton*, 413-441. New York.

Kośko A., Włodarczak P.
2018 A Final Eneolithic research inspirations: Subcarpathia borderlands between eastern and western Europe. *Baltic-Pontic Studies* 23: 259-291.

Kośko A., Klochko V.I., Olszewski A., Włodarczak P.
2018 Święte 11, feature 1149: sequence of funerary rites practiced by Corded Ware peoples and Early Bronze North Pontic cultures. *Baltic-Pontic Studies* 23: 69-92.

Kuzminova N.N.
1990 Paleoetnobotanicheskiy i palinologicheskiy analizy materialov iz kurganov nizhnego Podnestrovia. In E.V. Yarovoy (Ed.) *Kurgany eneolita – epokhi bronzy Nizhnego Podniestrovya,* 259-265. Kishinev.

Larsen C.S.
2015 *Bioarchaeology: Interpreting behavior from the skeleton.* 2nd Edition. Cambridge.

Lee-Thorp J.A., Sealy J.C., van der Merwe N.J.
1989 Stable carbon isotope ratio differences between bone collagen and bone apatite, and their relationship to diet. *Journal of Archaeological Science* 16: 585-599.

Lee-Thorp J.A.
2008 On isotopes and old bones. *Archaeometry* 50(6): 925-950.

Makarewicz C.A, Sealy J.
2015 Dietary reconstruction, mobility, and the analysis of ancient skeletal tissues: expanding the prospects of stable isotope research in archaeology. *Journal of Archaeological Science* 56: 146-158.

Murray M.L., Schoeninger M.J.
1988 Diet, status and complex social structure in Iron Age central Europe: some contributions of bone chemistry. In: D.B. Gibson, M.N. Geselowitz (Eds) *Tribe and polity in late Prehistoric Europe,* 155-176. New York.

O'Leary M.H.
1988 Carbon isotopes in photosynthesis. *Bioscience* 38(5): 328-336.

Olszewski A., Włodarczak P.
2018 Święte 11: cemetery of the Corded Ware culture. *Baltic-Pontic Studies* 23: 7-68.

Pate F.D.
1997 Bone chemistry and paleodiet: Reconstructing prehistoric subsistence-settlement systems in Australia. *Journal of Anthropological Archaeology* 16(2): 103-120.

Reitsema L.J., Kozłowski T., Makowiecki D.
2013 Human-environment interactions in medieval Poland: a perspective form the analysis of faunal stable isotope ratios. *Journal of Archaeological Science* 40: 3636-3646.

Svyatko S.V., Schulting R.J., Mallory J., Murphy E.M., Reimer P.J., Khartanovich V.I., Chistov Y.K., Sablin M.V.
2013 Stable isotope dietary analysis of prehistoric populations from the Minusinsk basin, southern Siberia, Russia: a new chronological framework for the introduction of millet to the eastern European steppe. *Journal of Archaeological Science* 40: 3936-3945.

Szczepanek A., Belka Z., Jarosz P., Pospieszny Ł., Dopieralska J., Frei K.M., Rauba-Bukowska A., Werens K., Górski J., Hozer M., Mazurek M., Włodarczak P.
2018 Understanding Final Neolithic communities in south-eastern Poland: New insights on diet and mobility from isotopic data. *PLoS One* 13: e0207748.

van der Merwe N.J., Vogel J.C.
1978 ^{13}C content of human collagen as a measure of prehistoric diet in late woodland North America. *Nature* 276: 815-816.

van Klinken G.J.
1999 Bone collagen quality indicators for paleodietary and radiocarbon measurements. *Journal of Archaeological Science* 26: 687-695.

van Klinken G.J., Richards M.P., Hedges R.E.M.
2002 An overview of causes for stable isotopic variations in pas European human populations, environmental, ecophysiological, and cultural effect. In: S.H. Ambrose, M.A. Katzenberg (Eds) *Biogeochemical approaches*

to paleodietary analysis, 39-63. New York, Boston, Dordrecht, London, Moscow.

Werens K., Szczepanek A., Jarosz P.
2018 Paleodieta przedstawicieli ludności kultury mierzanowickiej ze stanowisk 37 i 39 w Dobkowicach, pow. jarosławski. In: Jarosz P., Mazurek M., Szczepanek A., *Dobkowice, stan. 37 i 39, pow. jarosławski. Osady z wczesnego okresu epoki brązu na Przedgórzu Rzeszowskim.* Via Archaeologica Ressoviensia 14, 161-168. Rzeszów.