**An Integrated Bioarchaeological Approach to the Medieval ‘Agricultural Revolution’: A Case Study from Stafford, England, *c.* ad 800–1200**

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**Supplementary Material 4**

Isotopic Methods

# Sample selection and contamination screening

The crop remains were selected from archaeological contexts covering Phases 1, 2, and 3 and consisted of four cereal crops: rye, free-threshing wheat, barley, and oats. Stafford is atypical of the case studies used in FeedSax in that it is not a rural settlement. Nevertheless, the abundance of crop processing waste from the town indicates that some, probably most, of the cereals consumed in Stafford in this early period were grown in the immediate vicinity. What the samples analysed represent in terms of harvests, however, remains uncertain. As noted in the article, most derive from deposits of charred crop processing waste found in ovens or kilns and others from a timber-lined grain store. These deposits are likely to represent the combined harvests of several nearby farms. A target of ten grains per isotope sample was aimed for but not achievable due to limited grains per context, with samples containing on average five seeds. A target of 5–10 seeds per sample was based on research showing that samples of this size provide reasonable estimates of crop growing conditions, founded on analysis of modern grains from single growing contexts (Nitsch et al., 2015). The samples were examined microscopically to ascertain whether they were charred within the optimal charring window (Charles et al., 2015; Nitsch et al., 2015). The grains were cleaned of adhering soil by gentle scraping.

Fourier transform infrared spectroscopy analysis was conducted on a subset of the samples to identify possible contaminants. The selected samples included a range of different species, periods, and contexts, allowing an understanding of any contaminant within the assemblage. The results ruled out any significant contamination from humics, nitrates, or carbonates and the samples were not pre-treated.

# Isotopic analysis methods and analytical conditions

The samples were homogenised and weighed out, with every tenth sample duplicated to facilitate precision calculations. Given the low %N of the samples, the samples were run separately for carbon and nitrogen. The samples were analysed using a Sercon 20-22 EA-GSL isotope mass spectrometer operating in continuous flow mode at the Research Laboratory for Archaeology and the History of Art, University of Oxford. Both raw and drift corrected results were calculated using the in-house Alanine standard. Stable carbon isotopic compositions were calibrated relative to the VPDB scale using IAEA-CH7 and IAEA-CH6. Stable nitrogen isotopic compositions were calibrated relative to the AIR scale using IAEA-N2 and IAEA-N1 (Table S1). The calibration method followed was a two-point calibration, while a Kragten-type spreadsheet was used to calculate an individual sample’s measurement uncertainty using the in-house Alanine standard (Kragten, 1994). Measurement uncertainty as per Kragten averaged 0.18‰ for δ13C ranging from 0.1‰ to 0.2‰, while for δ15N it averaged at 0.36‰ ranging from 0.27‰ to 0.58‰.

Additional measurement and analytical uncertainty were observed using EMA-P2 (see Table S1) and sample duplicates (see Table S2) as per Szpak (2017). Measurement precision (the pooled standard deviations of the P2, calibration standards, and the sample duplicates) as per Szpak (2017) was calculated to be±0.12‰ for the δ13C and±0.5‰ for the δ15N. Systematic error was determined to be±0.1‰ for δ13C and±0.35‰ for δ15N based on the difference between the measured and known δ values of the check standard and the check standard’s long-term standard deviation. Total analytical uncertainty, calculated as per Szpak (2017), was estimated to be 0.15‰ for δ13C and 0.61‰ for δ15N. All calculations were performed using the statistical programming language R (3.5.0). The samples were not corrected for charring as they are not compared to uncharred or non-plant data. Full analytical results are provided in Table S3.

***Table S1.*** *Mean and standard deviation of all check and calibration standards for the analytical sessions from which the data presented in this article are derived.*

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Carbon Standards** | **Number** | **δ13C mean** | **δ13C Sd** | **Session** |
| CH6 | 3 | -10.45 | 0.06 | 180907 |
| CH7 | 3 | -32.15 | 0.06 | 180907 |
| P2 | 3 | -28.21 | 0.12 | 180907 |
| ALANINE | 6 | -27.17 | 0.03 | 180907 |
| CH6 | 6 | -10.45 | 0.11 | 180822A |
| CH7 | 5 | -32.15 | 0.11 | 180822A |
| P2 | 6 | -28.34 | 0.04 | 180822A |
| ALANINE | 11 | -27.11 | 0.18 | 180822A |
| CH6 | 4 | -10.45 | 0.10 | 180813a |
| CH7 | 4 | -32.15 | 0.07 | 180813a |
| P2 | 4 | -28.31 | 0.13 | 180813a |
| ALANINE | 8 | -27.13 | 0.08 | 180813a |
| CH6 | 5 | -10.45 | 0.03 | 181031 |
| CH7 | 4 | -32.15 | 0.01 | 181031 |
| P2 | 5 | -28.33 | 0.05 | 181031 |
| ALANINE | 7 | -27.23 | 0.07 | 181031 |
| **Nitrogen Standards** | **Number** | **δ15N mean** | **δ15Nsd** | **Session** |
| N1 | 7 | -0.40 | 0.29 | 180904 |
| N2 | 6 | 20.30 | 0.56 | 180904 |
| P2 | 6 | -1.45 | 0.42 | 180904 |
| ALANINE | 10 | -1.82 | 0.17 | 180904 |
| N1 | 6 | -0.40 | 0.55 | 180907A |
| N2 | 6 | 20.30 | 0.38 | 180907A |
| P2 | 6 | -1.34 | 0.15 | 180907A |
| ALANINE | 11 | -1.54 | 0.20 | 180907A |
| N1 | 3 | -0.40 | 0.28 | 190122A |
| N2 | 3 | 20.30 | 0.14 | 190122A |
| P2 | 4 | -2.10 | 1.11 | 190122A |
| ALANINE | 7 | -1.20 | 0.52 | 190122A |

***Table S2.*** *The δ13C and δ15N values for duplicated samples with the analytical sessions from which the Stafford material derives.*

|  |  |  |  |
| --- | --- | --- | --- |
| **Sample ID** | **Runfile C** | **δ13C Dulp A** | **δ13C Dulp B** |
| HF3279 | 180907 | -23.18 | -23.25 |
| HF3202 | 180907 | -23.81 | -24.09 |
| STT012 | 180822A | -22.36 | -22.46 |
| STM006 | 180822A | -25.67 | -25.64 |
| STM013 | 180822A | -23.19 | -23.05 |
| STM022 | 180822A | -24.77 | -24.79 |
| STM023 | 180813a | -24.66 | -24.87 |
| DAN052 | 180813a | -22.62 | -22.60 |
| GRT026 | 180813a | -23.58 | -23.61 |
| RYE215 | 181031 | -25.82 | -25.75 |
| SPT215 | 181031 | -27.06 | -27.02 |
| SPT215 | 181031 | -27.45 | -27.32 |
| STM003 | 181031 | -23.60 | -23.52 |
| STM013 | 181031 | -23.17 | -22.92 |
| STM020 | 181031 | -25.66 | -25.69 |
| STM021 | 181031 | -21.99 | -21.94 |
| **Sample ID** | **Runfile N** | **δ15N DulpA** | **δ15N DulpB** |
| STT012 | 180904 | 6.04 | 6.18 |
| STM006 | 180904 | 8.28 | 8.07 |
| STM013 | 180904 | 8.52 | 8.28 |
| STM022 | 180904 | 9.01 | 8.97 |
| DAN018 | 180907A | 5.49 | 5.93 |
| DKB008 | 180907A | 5.09 | 4.97 |
| DAN032 | 180907A | 2.83 | 2.63 |
| DAN025 | 180907A | 3.43 | 3.50 |
| SM002D | 181112 | 5.17 | 5.20 |
| STT002 | 181112 | 4.11 | 3.93 |
| STT009 | 181112 | 7.92 | 7.97 |
| STM017 | 181112 | 9.86 | 9.85 |
| STM021 | 181112 | 9.50 | 9.33 |

***Table S3.*** Provided separately in CSV format in Supplementary Material 5.

# Modern Carbon Analysis: Physiological Offset Between Oat and Other Cereals

Preliminary research was conducted on modern oat, rye, and free-threshing wheat to understand how δ13C values differ between the cereals species when grown under the same conditions. Material from two modern cereal crops and their contaminants was analysed to establish a preliminary understanding of any differences in δ13C values between the crops (Table S4). The results from the analysis of a rye crop with free-threshing wheat contaminants indicate that when these species are grown in the same field their grain δ13C values are not statistically significantly different (Table S4). This finding shows that a significant difference between archaeological rye and wheat may indicate that such crops were either cultivated in conditions of differential water availability, are from different years of cultivation, and/or were grown in different topographical locations. A second analysis, conducted on a rye crop with contaminants of oat, indicated that in the same cultivation conditions oat is statistically significantly different from rye and up to 2.5 ‰ lower in δ13C. The offset of oat δ13C from the other crops values suggests a physiological cause and is similar to, or possible slightly larger than, the expected offset of barley from free-threshing wheat (Wallace et al., 2013; Styring et al., 2017).

***Table S4.*** *Summary of analyses of rye, wheat and oat, including the mean δ13C value, standard deviation and t.test results.*

|  |  |  |  |
| --- | --- | --- | --- |
|  | **Crops** | **Mean** | **Statistical results** |
| **Analysis 1** | Rye and Wheat | Rye=-25.62± 0.34‰  Wheat =-25.09±0.11‰ | t(-2.6)2.3, p=0.1047 |
| **Analysis 2** | Rye and Oat | Rye= -26.07±0.11‰  Oat=-28.84±0.32‰ | t(-13.9) 2.5, p=0.002 |

# References

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