Relief food subsistence revealed by microparticle and proteomic analyses of dental calculus from victims of the Great Irish Famine

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Edited by Dolores R. Piperno, Smithsonian Institution, Washington, DC, and approved August 12, 2019 (received for review May 22, 2019)

Food and diet were class markers in 19th-century Ireland, which became evident as nearly 1 million people, primarily the poor and destitute, died as a consequence of the notorious Great Famine of 1845 to 1852. Famine took hold after a blight *(Phytophthora infestans)* destroyed virtually the only means of subsistence—the potato crop—for a significant proportion of the population. This study seeks to elucidate the variability of diet in mid–19th-century Ireland through microparticle and proteomic analysis of human dental calculus samples (n = 42) from victims of the famine. The samples derive from remains of people who died between August 1847 and March 1851 while receiving poor relief as inmates in the union workhouse in the city of Kilkenny (52°39′ N, −7°15′ W). The results corroborate the historical accounts of food provisions before and during the famine, with evidence of corn (maize), potato, and cereal starch granules from the microparticle analysis and milk protein from the proteomic analysis. Unexpectedly, there is also evidence of egg protein—a food source generally reserved only for export and the better-off social classes—which highlights the variability of the prefamine experience for those who died. Through historical contextualization, this study shows how the notoriously monotonous potato diet of the poor was opportunistically supplemented by other foodstuffs. While the Great Irish Famine was one of the worst subsistence crises in history, it was foremost a social disaster induced by the lack of access to food and not the lack of food availability.

bioarchaeology | paleoethnobotany | microfossil | potato | poverty

Ireland in the 19th century was characterized by political turbulence, economic decline, and drastic social and demographic changes (1). Poverty and destitution were widespread, and a highly stratified society denoted social class from a variety of factors, including diet. The potato (*Solanum tuberosum*), especially the Irish lumper cultivar, was a staple for the poor and destitute (2). For numerous reasons, by the 1840s, ∼40% of the population of Ireland had become utterly dependent on the potato for subsistence. The dependency on a single food source exposed people to significant risks and culminated in a devastating famine between 1845 and 1852 when a fungal blight (*Phytophthora infestans*) caused widespread destruction of the potato crop (Fig. 1). Nearly 1 million people died as a direct consequence of famine-induced starvation and disease. An estimated 200,000 of these famine-related deaths took place in the union workhouses (3), which were institutions for poverty relief that were introduced to Ireland following the Irish Poor Law Act of 1838 (4). When the potato harvest failed, vast quantities of food were imported as poor relief (5). This food was primarily made up of oatmeal from Britain and so-called "Indian meal" (maize) from the United States. The latter was to become an even more distinct social marker of poverty than the potato.

While the historical records of Victorian-period Ireland are vast, they generally do not reflect on the variability of the laboring classes' diet on an individual level. The aim and objectives of this study are to elucidate aspects of food availability and consumption patterns among the socially marginalized and impoverished in mid–19th-century Ireland through microparticle and proteomic analyses of dental calculus. The calculus derives from a subsample (n = 42) of archaeological skeletons of individuals (n = 970) who died while receiving poor relief in the union workhouse in Kilkenny City (*SI Appendix*, Fig. S1) between August 1847 and March 1851. The precise date of the remains—and the abundant historical resources pertaining to this period—enables a unique opportunity to use dietary analysis of dental calculus to evaluate both the historical and bioarchaeological sources and provide a holistic view of the condition of the mid–19th-century poor and destitute.

Results

Microparticles. Microparticle analysis was conducted on all samples, of which 41 contained a total of 383 starch granules (≥1 granule

Significance

This study provides direct evidence of the dependency on relief food in Ireland around the time of the Great Famine (1845 to 1852) through dental calculus analysis of archaeological human remains. The findings show a dominance of corn (maize) and milk from the identified foodstuffs and corroborate the contemporaneous historical accounts of diet and subsistence. It shows that microparticle and proteomic analyses, even when based on small archaeological samples, can provide a valid snapshot of dietary patterns and food consumption. The occurrence of egg protein, generally only included in the diet for the better-off social classes, also highlights how these analytical techniques can provide unanticipated insights into the variability of diet in historical populations.

Author contributions: J. Geber and M.T. designed research; J. Geber, M.T., A.S., P.N., and J.H. performed research; A.B. and C.W. contributed new reagents/analytic tools; J. Geber, M.T., A.S., J. Grossmann, and C.W. analyzed data; and J. Geber, M.T., A.S., J.H., and C.W. wrote the paper.

The authors declare no conflict of interest.

This article is a PNAS Direct Submission.

Data deposition: The mass spectrometry proteomics data have been deposited to the ProteomeXchange Consortium via the PRIDE partner repository, http://www.ebi.ac.uk/pride (dataset identifier PXD015002).

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This article contains supporting information online at www.pnas.org/lookup/suppl/doi:10.1073/pnas.1908839116/-/DCSupplemental.

First published September 9, 2019.

Fig. 1. "Destitution in Ireland. Failure of the potato crop" illustration was published in *The Pictorial Times* on 22 August 1846 (52). Image courtesy of the National Library of Ireland.

per sample); most of them were identified to 6 probable taxa (Table 1). Any granules measuring less than 10 μm were classified as unknown due to the difficulty in clearly distinguishing diagnostic features at this scale using light microscopy. The most dominant plant species identified was likely corn (*Zea mays*), which amounted to a total of 164 starch granules present in 38 samples (92.7%). There were 41 starch granules identified as probable oat (*Avena* spp.) present in 22 samples (53.7%). Probable wheat (*Triticum* spp.) granules ($n = 21$) were identified in 16 samples (39.0%). Five granules were identified as potato (*S. tuberosum*), and 5 were identified as probable malted barley (*Hordeum* spp.) (Fig. 2).

In addition to the identified taxa described above, there were 7 granules in 6 samples (14.6%) that derive from unidentified cereals (Poaceae), and there were a total of 140 granules across 37 samples (90.2%) that are of unknown origin, are less than 10 μm, or displayed nondiagnostic features. Of these unidentified granules, the majority are likely to derive from Poaceae starch. Also included among these are damaged starch microparticles (in all cases, they were not damaged to the point of losing visible extinction crosses). While it is well known that heat damages starch granules, studies have shown that it is still possible for some granules to survive unless the foods were boiled for more than 60 min (6–8), and these damaged granules may show the effects of cooking and food processing (6, 7).

Other findings include fungal material, hair, fibers, insect parts, and other unidentified plant and organic material (Dataset S1).

Table 1. Summary table of number of starch granules observed from dental calculus samples ($n = 42$) from the Kilkenny Union Workhouse by sex and age groups

	Sex			Age group (y)					
Taxa	M ($n = 22$)	F ($n = 19$)	? ($n = 1$)	13–17 ($n = 2$)	18–25 ($n = 4$)	26–35 ($n = 12$)	36–45 ($n = 18$)	≥46 ($n = 6$)	Total ($n = 42$)
Corn (*Z. mays*)	95	66	3	6	17	44	73	24	164
Oat (*Avena* spp.)	20	21	0	2	8	7	13	11	41
Wheat (*Triticum* spp.)	9	12	0	0	5	4	10	2	21
Malted barley (*Hordeum* spp.)	3	2	0	1	0	1	3	0	5
Cereal (Poaceae)	4	2	1	1	0	0	3	3	7
Potato (*S. tuberosum*)	3	2	0	0	1	1	2	1	5
Indeterminable	88	50	2	14	10	29	59	28	140
Total	222	155	6	24	41	86	163	69	383

F, female; M, male; ?, indeterminable.

ANTHROPOLOGY

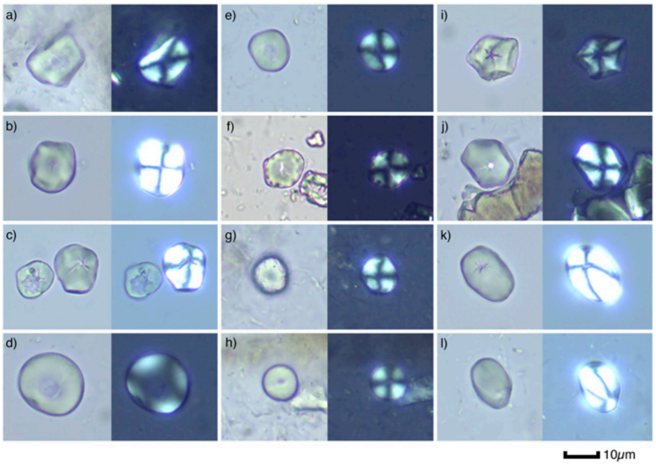

Fig. 2. Examples of starches observed in the microparticle analysis: (*A*–*C*) corn (*Z. mays*), (*D* and *E*) malted barley (*Hordeum* spp.), (*F*–*H*) wheat (*Triticum* spp.), (*I* and *J*) oat (*Avena* spp.), and (*K* and *L*) potato (*S. tuberosum*).

Some of the unidentified organic material may be chaff from unprocessed or poorly processed cereals, and it possibly reflects food adulteration. It may also be microparticles that derive from nondietary sources (9), such as from beddings that, for the poor, were composed of nothing more than chaff and straw both before and during institutionalization (10). The hair and fibers were present in 9 samples, with a notably high concentration in dental calculus from a 26- to 35-y-old female (CCCXXI).

Proteomics. Dental calculus was extracted from 14 individuals, and they were selected based on having deposits of dental calculus ≥1 mg for potential analysis. Seven samples contained animal (milk or egg) proteins (*SI Appendix*, Fig. S4), and 6 samples contained glyceraldehyde 3-phosphate dehydrogenase (GAPDH), a ubiquitous cellular protein of probable plant origin (Table 2) (11). Modifications expected for ancient/historical samples, such as deamidation (N, Q), were observed (Dataset S2). Peptides from the milk whey protein beta-lactoglobulin (BLG) were positively identified in 7 of the samples originating from 5 males and 2 females. Taxonomically diagnostic sequence variants in the BLG peptides confirmed the specific consumption of cattle (*Bos*; $n = 5$) and goat (*Capra*; $n = 1$) milk, and 3 individuals consumed bovid milk of ambiguous origin (cattle/sheep or sheep/goat). Cattle milk seems to have been the dominant milk source, and it is likely that all 7 individuals consumed cattle milk. Peptides from the egg protein ovalbumin, originating from domestic chicken (*Gallus*), were also identified in 2 males and 1 female, and each of these individuals also consumed milk. The cellular protein GAPDH has been previously found to be the most frequently recovered plant protein in archaeological dental calculus (12), and GAPDH peptides of probable plant origin were identified in 6 individuals (3 males, 3 females). Unfortunately, the peptide sequences are highly conserved among green plants (Viridiplantae) as well as a small number of bacterial species, and they are, therefore, not specific enough to identify individual taxa.

Discussion

While the potato was the staple diet for the poor throughout Ireland, there were regional differences regarding agricultural and horticultural produce and dietary patterns across the island. In the west, where the social conditions were most deprived, oatmeal was rarely a dietary component, while the opposite was true in the northeast. Bread was mostly consumed in the east, and milk was a common component in the diet in the southwest, the southeast, and the north (13). Local agriculture in Kilkenny was dominated by grain and cattle production, one of the foundations of the relative prosperity of the city (14). Other than cereals and vegetables, markets were well supplied with sea fish, meat, and reportedly, even exotic fruits, such as peaches, melons, grapes, and pineapple (15). Much of the agricultural produce, however, was destined for the export market, and the diet of the average laborer in Kilkenny would corroborate what was seen elsewhere in Ireland. An account from the early 1840s stated that occupants on even sizable County Kilkenny farms of 70 to 100 acres would generally only have "potatoes and milk, stirabout, or oaten-bread and milk for breakfast and supper, and generally potatoes and butter, but once or twice herrings or butcher-meat, for dinner" (16) (stirabout is porridge made from oats, Indian meal, or both).

In accordance with the Poor Law, the composition of the Kilkenny Union Workhouse diet (*SI Appendix*, Table S1) was intentionally dire. Before 1846, potatoes were a staple and supplemented with milk rations that would have reflected the diet for many of the inmates before admission into the institution. During the famine, potatoes were chiefly replaced with Indian meal. In the

Table 2. Summary table of the dietary proteins identified in dental calculus samples analyzed through proteomics ($n = 10$) by sex and age groups

Skeleton identification no.	Age group (y)	Sex	Extraction identification no.	Putative dietary protein	Total PSMs identified	Protein taxonomic assignment
CXCV	36–45	M	Z527	BLG	24	Cattle (Bovinae) or sheep (*Ovis*)
CCXXVII	≥46	M	Z526	BLG	59	Cattle (*Bos*) and goat (*Capra*)
CCXXVII	≥46	M	Z526	GAPDH	6	Probable green plant (Viridiplantae)
CCXXVII	≥46	M	Z526	Ovalbumin	7	Chicken (*Gallus*)
CCXXXIV	26–35	F	Z321	GAPDH	4	Probable green plant (Viridiplantae)
CCLXXXII	36–45	M	Z523	BLG	10	Cattle (*Bos*)
CCCXVIII	≥46	M	Z528	GAPDH	10	Probable green plant (Viridiplantae)
CCCXCVIII	36–45	M	Z534	BLG	8	Cattle (*Bos*) and sheep/goat (Caprinae)
DLXIV	18–25	F	Z533	BLG	3	Cattle (*Bos*)
DLXIV	18–25	F	Z533	GAPDH	4	Probable green plant (Viridiplantae)
DLXIV	18–25	F	Z533	Ovalbumin	4	Chicken (*Gallus*)
DLXXII	36–45	F	Z529	GAPDH	10	Probable green plant (Viridiplantae)
DCLXXXIII	36–45	M	Z532	BLG	11	Cattle (*Bos*)
DCLXXXIII	36–45	M	Z532	GAPDH	7	Probable green plant (Viridiplantae)
DCLXXXIII	36–45	M	Z532	Ovalbumin	6	Chicken (*Gallus*)
DCCCXXIX	26–35	F	Z531	BLG	8	Cattle (Bovinae) or sheep (*Ovis*)

A peptide summary is provided in Dataset S2. F, female; M, male; PSM, peptide spectrum match.

latter years of the famine, a vegetable soup was introduced as part of the adult food rations, although at rations of only half a pint for dinner. This soup consisted of 5 ounces of rice, 5 ounces of oatmeal, 12 pounds of turnips (swedes), 2 pounds of parsnips, and onions with pepper and salt as required per gallon (17). Some meat was provided as part of the medical treatment in the workhouse infirmary (18), and for some periods, the minute books reveal the quantities of meat stored in the house. In the last week of February 1851, for instance, 390 pounds of meat were recorded in the food inventory. On those dates, the same records show that the union was providing indoor relief for 4,282 people! Other than flavor enhancers, such as pepper and allspice, the minute books also reveal other food products, such as arrowroot, sugar, broth, cocoa, port and sherry wine, whiskey, and porter. These are likely, just as the meat, to have been provisioned only for inmates treated in the workhouse infirmary.

Historical Contextualization of Results. The microparticle and proteomic analyses of the dental calculus samples exhibit a dominance of foodstuffs that are consistent with the 19th-century Irish laborer's diet and relief food consumed during the famine, suggesting that the calculus buildup in the analyzed subsample reflects tartar accumulations prior to and/or during life in the workhouse. This notion is primarily argued from the dominance of corn deriving from Indian meal, which was a central component of the workhouse diet during the famine, although it had also occasionally been distributed as poor relief in County Kilkenny on previous occasions (19). Stable isotope analyses conducted to date on a subsample of the skeletal remains have also indicated a C4 dietary input (maize), which further reflects the relief food dependency for the poor before and during the famine (20). The evidence of oat starch granules in the calculus samples could reflect both the relief food and/or the prefamine diet of these individuals.

The high occurrence of identifiable corn starch granules may also reflect the documented difficulty in processing the grain; Irish millers generally lacked the knowledge of how to sufficiently grind Indian corn, and the course grind may have allowed for the starch granules to survive the boiling process. The fact that the starch granules from corn dominate the samples also highlights how the experience of the famine was a prolonged period of suffering and struggle and that death was not instant. While Indian meal would have helped to combat hunger, it may ultimately also have caused further health deprivations. The corn was profoundly inferior in its nutritional value, as it, at the time, was improperly prepared, with a devastating effect on the health of the already weakened and frail. This was largely the result of a European rejection of adopting the traditional indigenous American method of preparing maize through the process of nixtamalization (alkaline cooking), which releases niacin from the grains (21). As a consequence, niacin deficiency—resulting in pellagra—is likely to have been an inadvertent consequence of the relief food distributed to the starving poor in Ireland during the famine (22).

As stated above, the workhouse diet included a soup, but its vegetable ingredients were not identified by protein or microscopic analysis in this study. This is likely due to the quick gelatinization process of vegetable starches (tubers and grains) during cooking (23, 24) as well as incomplete proteomic reference databases and the lack of identifiable microparticle production of some plants (onions, swedes). Starch granules from rice (*Oryza sativa*), another ingredient in the soup, could potentially be identified from microparticle analysis, as they gelatinize at much higher temperatures and have a higher lipid content (24). However, these granules would measure less than 10 µm in size (24) and therefore, would all be present among the unidentifiable microparticles found in this study. The absence of any grass/grain phytoliths in the dental calculus suggests that the plant foods that people ate were processed and not wild. Phytoliths are generally found in the husks and skin of grains, and in preindustrial archaeological dental calculus—where processing was minimal or done by hand—phytoliths are commonly found (25, 26).

The gelatinization of starch granules during cooking may also explain the low frequency of potato and the high frequency of corn starch granules in the calculus samples, although—naturally in the context of this study—this may also reflect crop availability. The gelatinization process of potato starch begins around a temperature of ∼30 °C, and therefore, boiling, which was the preferred method for cooking potatoes in 19th-century Ireland, would have completely gelatinized the potato starch granules (27). Corn, however, has a much higher gelatinization temperature (28). The fact that some potato starch granules were nevertheless identified in a limited number of samples may reflect the way that the poor prepared the vegetable.

> The cabin-boiled potato was dressed in two ways: with and without the *bone* or the *moon*, as it is universally called by the genuine Irish. In the latter form, the potato was done to the heart, equally mealy throughout, and bursting its skin with fatness. This was the supper when children and young persons were to partake of the meal; but when much work was to be done, or a long fast to be endured, the heart or central nucleus of the potato was allowed, by checking the boil at a particular period, to remain parboiled, hard and waxy; and when the rest of the potato had been masticated in the usual manner, this hard lump, about the size of a small walnut, was bolted; and in this manner nearly a stone of the root was taken into the stomach of the Irish labourer per diem. (29)

The presence of the milk protein BLG in the calculus of half of the tested individuals supports the historical records of milk being an important liquid component of the poor laborer's diet. Somewhat surprising is that only 1 instance of BLG from goat (*Capra*) and a second from sheep/goat (Caprinae) were identified given that the goat—generally referred to as the "poor man's cow"—played a particularly important role in the Irish domestic economy due to, what was said, the "impoverished state of the country" (30). However, additional trypsin cut sites in caprine BLG may lead to smaller peptides that are less likely to be identified through liquid chromatography with tandem mass spectrometry (LC-MS/MS) analysis; thus, an absence of these peptides does not necessarily indicate that goat milk was not widely consumed. If indeed the specific identification of cattle milk as opposed to other ruminant taxa is accurate, the fact that milk from cattle is dominating the identifications may also suggest that it derives primarily from the workhouse diet, as milk was purchased by the Kilkenny Union at large quantities every week from a limited number of suppliers, and this is likely to indicate that it was derived from a larger and more commercial production setup.

Diet Variability and Food Access during the Time of the Great Irish Famine. The shame associated with poor relief in the form of food is mentioned in local folklore that tells of how receiving stirabout made from Indian meal was gravely humiliating for a great number of people who, prior to the blight, had considered themselves as "respectable farmers" (31). For many others, however, the desperate struggle for subsistence—and the associated perceived stigma—had been a constant reality of their existence long before the famine. A German visitor to Ireland gave one particularly evocative account from Kilkenny City where he arrived by coach in August 1837.

> At Kilkenny there is an old castle, and innumerable beggars…The coach is besieged by them, and their cries resounds from all sides, and in all gradations of old and young voices…I saw a mother pick up the gooseberry skins which one of the travellers had spit out, and put them into the mouth of her child. I never [before] saw any thing like this. (32)

For obvious reasons, the situation for the poor and destitute had declined gravely a decade later, and folklore tells of how people in Kilkenny, just as elsewhere in Ireland, had resorted to eating grass and weeds during the famine (33). Local accounts also state that, while the poor and the laboring classes suffered greatly, the fertile lands in the county generated good crops of wheat during the years of the potato blight, but this food was bought up by the local gentry who made profits by exporting it for sale at English markets (34). Other recorded narratives, however, tell of how locally produced oats and wheat had, indeed, been distributed in County Kilkenny as famine relief food (35).

While major aspects of the relief food provided by the Kilkenny Union are evidenced through this study, there were also dietary components indicated from the microparticle and proteomic analyses that show aspects of the variability of the laborer's diet in 19th-century Ireland. Proteomic analysis identified the egg protein ovalbumin in the dental calculus of 3 individuals. Eggs were regarded as "luxury food" for the working classes (13) and thereby, also a dietary class marker. Although it was not uncommon for the peasantry to keep poultry, eggs were not eaten except for, perhaps, during celebratory occasions. Eggs were, just as much as the wheat crop, destined for the export market, or as one Irish laborer in the 1830s stated, "We eat none of them; they go to our rent, or to put a shoe on our foot, or a spade in our hands" (36).

The evidence of egg protein through this study is highlighting how the prefamine experience and living conditions might have varied for those people who were forced to resort to the Irish workhouses in the 1840s. The evidence of probable wheat in the dental calculus of some individuals from the Kilkenny Union Workhouse can also be viewed in the same light, although it is possible that the wheat derives from the occasional bread that was part of the workhouse diet or from an as yet unidentified local wild grass. Further references to the crop in famine-period records from Kilkenny tell of how wheat was being "crop-lifted" by desperate people (37), and there were also several reports of "bread riots" occurring in the city during the famine (38).

Conclusion

The social, political, and economic historical background of the Great Irish Famine is very complex, and the term "The Irish Potato Famine" (generally never used in Ireland) is problematic for that reason. While the famine was a subsistence crisis initiated by the destruction of the potato crop blight, it was much more than a natural disaster relating to a single vegetable. Prevailing laissez-faire economic convictions profoundly influenced the political response to the food crisis that occurred, and vast amounts of food products were exported from Ireland while the poor starved (39). There was also an undoubtedly colonial dimension to these economic policies, where Ireland and its primarily Catholic population—which following the Act of Union in 1801, were governed directly by a British government from Westminster—were subjugated through various political means (40).

As made evident through this study, scientific evaluations using microparticle and proteomic analytical techniques of archaeological dental calculus can provide complimentary snapshots of overall diets even from exceptionally well-contextualized and well-recorded historical samples. This study suggests that diet variability of the poor was limited and expressed equally across both sexes among the poor in Ireland during the time of the Great Famine. When interpreting the findings in their historical and cultural context, the evidence of eggs (and probably also wheat) also indicates how the food subsistence pattern for the laboring classes was opportunistic. Contemporary 19th-century accounts would state that the potato was the food of choice for the poor (41), but this was a truth with modification. When commenting on whether the peasantry preferred potatoes over meal or bread, one laborer from the west of Ireland during the 1840s replied: "Why would we prefer that, that we feed our pigs on to better food? Don't you like it better yourself, and why shouldn't we? Never believe them that would want to make you think that we'd eat wet lumpers if we could get good bread" (42). This notion is further indicated from this study, which has provided nuanced insights into how socially marginalized people sought to maintain their subsistence while enduring a life of constant hardship and unimaginable struggles.

Materials and Methods

A mass burial ground adjacent to the former Kilkenny Union Workhouse, Kilkenny City, Ireland, was excavated in 2006. A minimum of 970 individuals from 63 burial pits were recovered. The skeletal remains were analyzed following standard osteological methods. Dental calculus was sampled from individual teeth extracted from a subsample of 42 skeletons prior to the reburial in 2010 (*SI Appendix* has details).

Microparticles were extracted from 42 dental calculus samples (on average ~3 × 3 mm) using the ethylenediaminetetraacetic acid (EDTA) extraction method described in Tromp et al. (43) and briefly reviewed in *SI Appendix*. Starch granules were analyzed primarily using published studies and descriptions (24, 44–50) as well as a reference collection; measurements and descriptions of relevant taxa are included in Dataset S3. Identifications were made based on the size (maximum width), shape, and distinguishing features, such as visible lamellae, surface pitting, pressure facets, and visible and/or cracked hilum (additional details are in *SI Appendix* and Datasets S3 and S5).

Proteins were extracted from decalcified dental calculus samples according to guidelines recommended by Hendy et al. (51). Extracted peptides were analyzed by LC-MS/MS using a Q-Exactive HF mass spectrometer (Thermo Scientific) coupled to an ACQUITY UPLC M-Class system (Waters AG) (*SI Appendix* has additional details). Tandem mass spectra were converted to Mascot generic files by MSConvert version 3.0.11781 with the 100 most intense peaks in each spectrum. All MS/MS samples were analyzed using Mascot (Matrix Science; version 2.6.0). Mascot was set up to search the databases SwissProt_2017_07.fasta and uniprot_trembl_2017_07, assuming the digestion enzyme trypsin and selecting the automatic decoy option (*SI Appendix* has additional details). Scaffold (version Scaffold_4.8.9; Proteome Software Inc.) was used to validate MS/MS-based peptide and protein identifications. Peptide identifications at a local false discovery rate (FDR) of less than 1.0% (Scaffold Local FDR algorithm) and protein identifications at an FDR of less than 5.0% and supported by at least 3 identified peptides were accepted (*SI Appendix* has additional details). Raw data files are available through the ProteomeXchange Consortium via the PRIDE partner repository (accession no. PXD015002).

ACKNOWLEDGMENTS. We thank the editor and the anonymous reviewers for their constructive criticism, helpful comments, and suggestions, which have improved the paper. This study is made possible thanks to permission and support from the Irish Antiquities Division of the National Museum of Ireland (NMI). Thanks are also due to Dr. Regina Sexton and Dr. Laurence Geary for input on food culture in 19th-century Ireland, and to Dr. Christian Trachsel for assistance with protein mass spectrometry. The archaeological excavation at the Kilkenny Union Workhouse mass burials was undertaken by Margaret Gowen & Co. Ltd. under license 05E0435 from the NMI. Laboratory analyses undertaken for this study were funded by the Max Planck Institute for the Science of Human History; the Department of Anatomy of the University of Otago; research grants from Johan and Jakob Söderberg's Foundation and the Royal Irish Academy in partnership with the National Monuments Service; Wellcome Trust Grant 096435/Z/11/Z; and US NSF Grant BCS-1523264.

1. C. Ó Gráda, *Ireland before and after the Famine: Explorations in Economic History, 1800–1925* (Manchester University Press, 1993).
2. P. M. A. Bourke, The use of the potato crop in pre-Famine Ireland. *J. Stat. Soc. Inq. Soc. Irel.* **21**, 72–96 (1968).
3. C. Ó Gráda, "Mortality and the Great Famine" in *Atlas of the Great Irish Famine, 1845–52*, J. Crowley, W. J. Smyth, M. Murphy, Eds. (Cork University Press, 2012), pp. 170–179.
4. J. O'Connor, *The Workhouses of Ireland: The Fate of Ireland's Poor* (Anvil Books, 1995).
5. M. S. Harzallah, Food supply and economic ideology: Indian corn relief during the second year of the Great Irish Famine (1847). *Historian* **68**, 305–323 (2006).
6. A. G. Henry, H. F. Hudson, D. R. Piperno, Changes in starch grain morphologies from cooking. *J. Archaeol. Sci.* **36**, 915–922 (2009).
7. A. Crowther, The differential survival of native starch during cooking and implications for archaeological analyses: A review. *Archaeol. Anthropol. Sci.* **4**, 221–235 (2012).
8. S. L. Schnorr, A. N. Crittenden, A. G. Henry, Impact of brief roasting on starch gelatinization in whole foods and implications for plant food nutritional ecology in human evolution. *Ethnoarchaeology* **8**, 30–56 (2016).
9. A. Radini, E. Nikita, S. Buckley, L. Copeland, K. Hardy, Beyond food: The multiple pathways for inclusion of materials into ancient dental calculus. *Am. J. Phys. Anthropol.* **162** (suppl. 63), 71–83 (2017).

10. Poor Law Commission, Poor Inquiry (Ireland). Appendix (E.) (Majesty's Stationary Office, 1836).
11. A. Scott, C. Warinner. Project PXD015003. Proteomics Identifications (PRIDE) Archive. http://doi.org/10.6019/PXD015002. Deposited 13 August 2019.
12. J. Hendy *et al*., Proteomic evidence of dietary sources in ancient dental calculus. *Proc. Biol. Sci.* **285**, 20180977 (2018).
13. L. Kennedy, P. S. Ell, E. M. Crawford, L. A. Clarkson, *Mapping the Great Irish Famine: A Survey of the Famine Decades* (Four Courts Press, 1999).
14. D, On the agriculture of the county of Kilkenny. *Q. J. Agric.* **9**, 475–495 (1839).
15. W. Tighe, *Statistical Observations Relative to the County of Kilkenny, Made in the Years 1800 & 1801* (Graisberry and Campbell, 1802).
16. Anonymous, *The Parliamentary Gazetteer of Ireland, Adapted to the New Poor-Law, Franchise, Municipal and Ecclesiastical Arrangements, and Compiled with a Special Reference to the Lines of Railroad and Canal Communication, as Existing in 1844–45; Illustrated by a Series of Maps, and Other Plates; and Presenting the Results, in Detail, of the Census of 1841, Compared with That of 1831* (A. Fullarton and Co., 1846), vol. 2.
17. Board of Guardians, *The Kilkenny and Leinster Commercial and Literary Advertiser*, 13 December 1848.
18. Kilkenny Union Board of Guardians, "Minutes of Kilkenny Union Board of Guardians meeting 5 October" (Kilkenny County Library, Local Studies, 1842).
19. T. de Bhaldraithe, *The Diary of an Irish Countryman 1827–1835. A Translation of Cín Lae Amhlaoibh* (Mercier Press, 1979).
20. J. Beaumont, J. Montgomery, The Great Irish Famine: Identifying starvation in the tissues of victims using stable isotope analysis of bone and incremental dentine collagen. *PLoS One* **11**, e0160065 (2016).
21. E. C. Ellwood, M. P. Scott, W. D. Lipe, R. G. Matson, J. G. Jones, Stone-boiling maize with limestone: Experimental results and implications for nutrition among SE Utah preceramic groups. *J. Archaeol. Sci.* **40**, 35–44 (2013).
22. E. M. Crawford, "Indian meal and pellagra in nineteenth-century Ireland" in *Irish Population, Economy, and Society*, J. M. Goldstrom, L. A. Clarkson, Eds. (Essays in Honour of the Late K. H. Connell, Clarendon Press, 1981), pp. 113–133.
23. R. F. Tester, J. Karkalas, Swelling and gelatinization of oat starches. *Cereal Chem.* **73**, 271–277 (1996).
24. J. Waterschoot, S. V. Gomand, E. Fierens, J. A. Delcour, Production, structure, physicochemical and functional properties of maize, cassava, wheat, potato and rice starches. *Starke* **67**, 14–29 (2015).
25. E. Norström, R. Gustavsson, F. Molin, S. Gummesson, Micro-fossil analysis of Mesolithic human dental calculus, Motala, Sweden–Indications of health status and paleo-diet. *J. Archaeol. Sci. Rep.* **67**, 101866 (2019).
26. A. Radini, E. Nikita, L. M. Shillito, "Human dental calculus and a medieval urban environment" in *Objects, Environment, and Everyday Life in Medieval Europe*, B. Jervis, L. G. Broderick, I. G. Sologestoa, Eds. (Brepols Publishers, 2016), pp. 297–313.
27. T. Shiotsubo, Gelatinization temperature of potato starch at the equilibrium state. *Agric. Biol. Chem.* **48**, 1–7 (1984).
28. M. Schirmer, M. Jekle, T. Becker, Starch gelatinization and its complexity for analysis. *Starke* **67**, 30–41 (2015).
29. W. Wilde, The food of the Irish. Dublin Univ. Mag. 43, 127–146 (1854).
30. J. Wilson, *British Farming: A Description of the Mixed Husbandry of Great Britain* (Adam and Charles Black, 1862).
31. Irish Folklore Commission/Department of Education and the National Irish Teacher's Organisation, "'Famine times,' told by an unknown informant, Paulstown, Co. Kilkenny" in *Schools' Folklore Collection* (National Folklore Collection, University College Dublin, 1937–1938), vol. 0861, p. 396.
32. F. von Raumer, *England in 1835: Being a Series of Letters Written to Friends in Germany, during a Residence in London and Excursions into the Provinces* (Carey, Lea, and Blanchard) 1836).
33. Irish Folklore Commission/Department of Education and the National Irish Teacher's Organisation, "'The Famine,' told by Mr Thomas Cuddihy (50 years), Pilltown, Co. Kilkenny to Mr John Ryan (12 years), Pilltown, Co. Kilkenny" in *Schools' Folklore Collection* (National Folklore Collection, University College Dublin, 1937–1938), vol. 0842, p. 259.
34. Irish Folklore Commission/Department of Education and the National Irish Teacher's Organisation, "'Knocktopher,' told by Fr Dwyer, Knocktopher, Co. Kilkenny to L. Geoghegan, Knocktopher, Co. Kilkenny" in *Schools' Folklore Collection* (National Folklore Collection, University College Dublin, 1937–1938), vol. 0848, pp. 304–322.
35. Irish Folklore Commission/Department of Education and the National Irish Teacher's Organisation, "Historic–Famine period–Black '47,' told by Mr. Denis Carroll (60 years), Templemartin, Co. Kilkenny" in *Schools' Folklore Collection* (National Folklore Collection, University College Dublin, 1937–1938), vol. 0859, pp. 373–374.
36. C. I. Johnstone, "True Tales of the Irish Peasantry, as Related by Themselves" Selected from the Report of the Poor Law Commissioners (William Tait, 1836).
37. Anonymous, News of the week. Ireland. Commencement of crop-lifting. *The Economist, Weekly Commercial Times, Bankers' Gazette, and Railway Monitor: A Political, Literary, and General Newspaper* **8**, 937–938 (1850).
38. Food riots in Kilkenny. *Morning Advertiser*, 12 June 1848.
39. C. Kinealy, Food exports from Ireland 1846–47. *Hist. Irel.* **5**, 32–36 (1997).
40. T. McDonough, Ed., *Was Ireland a Colony? Economics, Politics, and Culture in Nineteenth-Century Ireland* (Irish Academic Press, 2005).
41. A. Bourke, *'The Visitation of God'? The Potato and the Great Irish Famine*, J. Hill, C. Ó. Gráda, Eds. (Lilliput Press, 1993).
42. T. M. Ray, *Report on the Irish Coercion Bill, the Causes of Discontent in Ireland, Condition of the People, Comparative Criminality with England, Remedial Measures, Etc. Etc* (J. Browne, 1846).
43. M. Tromp, H. Buckley, J. Geber, E. Matisoo-Smith, EDTA decalcification of dental calculus as an alternative means of microparticle extraction from archaeological samples. *J. Archaeol. Sci. Rep.* **14**, 461–466 (2017).
44. R. Torrence, H. Barton, Eds., *Ancient Starch Research* (Left Coast Press, 2006).
45. A. G. Henry, D. R. Piperno, Using plant microfossils from dental calculus to recover human diet: A case study from Tell al-Raqā'I, Syria. *J. Archaeol. Sci.* **35**, 1943–1950 (2008).
46. T. Juhola, H. Etu-Sihvola, T. Näreoja, J. Ruohonen, Starch analysis reveals starchy foods and food processing from Finnish archaeological artefacts. *Fennosc. Archaeol.* **31**, 79–100 (2014).
47. D. Nadel, D. R. Piperno, I. Holst, A. Snir, E. Weiss, New evidence for the processing of wild ceral grains at Ohalo II, a 23 000-year-old campsite on the shore of the Sea of Galilee, Israel. *Antiquity* **86**, 990–1003 (2012).
48. D. R. Piperno, E. Weiss, I. Holst, D. Nadel, Processing of wild cereal grains in the Upper Palaeolithic revealed by starch grain analysis. *Nature* **430**, 670–673 (2004).
49. X. Yang, L. Perry, Identification of ancient starch grains from the tribe Triticeae in the North China Plain. *J. Archaeol. Sci.* **40**, 3170–3177 (2013).
50. M. Li, X. Yang, Q. Ge, X. Ren, Z. Wan, Starch grain analysis of stone knives from Changning site, Qinghai Province, Northwest China. *J. Archaeol. Sci.* **40**, 1667–1672 (2013).
51. J. Hendy *et al*., A guide to ancient protein studies. *Nat. Ecol. Evol.* **2**, 791–799 (2018).
52. Irish agitation and destitution. *The Pictorial Times*, 22 August 1846.