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The role of modern malnutrition in modelling Roman malnutrition: Aid or anachronism?

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ABSTRACT

This paper shows how insights pertaining to modern malnutrition may be of use in modelling Roman malnutrition. It also points out some of the dangers and pitfalls of applying modern insights, data and *a priori* suppositions to the past. We approach this topic from two perspectives that challenge some of the implicit and explicit assumptions regarding the similarities and dissimilarities between ancient and modern malnutrition. First we argue that a degree of malnutrition is part of the human condition and that economic growth may only limitedly remedy it. Indications of past malnutrition are therefore of limited value in judging economic performance. Secondly we show that the nutritional value of cereals has been underestimated by historians and archaeologists, especially in terms of trace element content (colloquially: ‘minerals’), while their role in the diet has been overestimated. Both aspects have undergone great changes during the Green Revolution of the mid-20th century due to dilution due to extreme yield increases and unforeseen side effects of genetic modification. As neither Roman nor any other pre-20th century cereals could have been subject to such changes, our view on the role of cereals in Roman diet and nutrition needs to be revised.

1. Introduction: the argument

This review paper aims to show how insights pertaining to modern malnutrition may be of use in modelling Roman malnutrition. However, it also points out some of the dangers and pitfalls of applying modern insights, data and *a priori* suppositions to the past. We will approach this topic from two perspectives that challenge some of the implicit and explicit assumptions regarding the similarities and dissimilarities between ancient and modern malnutrition. The first section provides a brief overview of how the approach of modern historians to malnourishment in the Roman world developed over the past decades. In the second section we will emphasize the ubiquity of malnutrition and its many forms in the modern world and argue that malnutrition was part of the human condition in the past as it is in the present, and very likely, the foreseeable future. On the one hand, we aim to contextualize the occurrence and evidence for ancient malnutrition, while on the other hand we will show how the modern relationship between economic growth, labour productivity and malnutrition may be of help in modelling this relationship for the Roman period. In the third section we will discuss some dissimilarities between ancient and modern malnutrition. We will focus on the effects of the 20th century Green Revolution, which while it increased agricultural productivity, it also

negatively affected the micronutrient content of cereals and increased the proportion of cereals in the diet. We will point out the aspects and processes responsible for modern malnutrition that are anachronistic if applied to the Roman period. We will argue that the use of post-Green Revolution biochemical insights, agro-statistics and ethnographic data has affected our view of the nutritional quality of cereals and of the diversity of past diets, leading to an overestimation of the role of cereals.

2. Roman diet and nutritional deficiencies: past and current perspectives

The research by Robert Fogel (2004, 2012) and Amartya Sen (1981) on long-term developments in living standards and nutrition has been very influential on ancient historians and archaeologists in determining their research questions and expectations regarding diet and (mal)nutrition in the ancient world. Fogel pointed out that widespread malnutrition among the workforce in early modern Europe severely limited labour productivity. Social inequality, low labour productivity, and prevalent diseases, which impaired the ability of the human body to absorb nutrients despite a potentially adequate diet, kept nutritional status and living standards low. Fogel explained that economic growth

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in the recent past to a significant extent followed from improvements in health care and diet (Fogel, 2004). Some groups were more vulnerable in this regard than others, as Sen pointed out. Using the concept of entitlement, he identified women and children, the urban poor and rural day-labourers in particular as being in a weak position and faring economically worse than their male counterparts (Sen, 1981). Inspired by these scholars, Peter Garnsey in his studies of diet and nutrition in the ancient world rightly spoke out against the naïve idea that societies that boasted such tremendous achievements as the Greeks and Romans did, must have consisted of healthy, well-fed populations (Garnsey, 1999). While scholars working in ancient history lacked the data on food consumption available to Fogel, there was reason to postulate similar – if not worse – levels of malnourishment and malnutrition in the Roman world. Skeletal remains on the one hand indicated a high occurrence of nutritional deficiencies as a result of inadequate intake or disease; on the other hand a relatively short stature among ancient populations was interpreted as reflecting low living standards.

Recently, however, viewpoints on the omnipresence of malnutrition in the pre-industrial world have significantly changed. Gregory Clark (2007) offers a strong argument against the teleological assumption that there is a steady upward trend regarding diet and nutrition in human history. Long-term developments in agricultural productivity – the invention of agriculture itself, he stresses (cf. Armelagos et al., 1991) – had not resulted in steadily better fed people, but only in more people, who generally had to work harder than their predecessors (cf. Boserup, 1965). In other words, simply because 18th-century France or 19th-century England, or modern developing countries for that matter, counted many malnourished individuals does not mean that the same must have applied to ancient Rome.

Stature has been used in historical research as a proxy for living standards and nutrition, indicating general long-term changes between societies. One such study pointed out that average height increased after the fall of the Roman Empire, only to drop again when population levels rose in the high Middle Ages; average height then increased again when the Black Death of the 14th century decimated the European populace. In other words, high population density in the Roman world had put pressure on living standards, which was reflected in shorter stature (Koepeke and Baten, 2005; likewise Giannecchini and Moggi-Cecchi, 2008, cf. Kron, 2005). Apart from the small and often biased data sets for some periods (for instance, most Roman skeletons derive from urban graveyards, cf. Flohr, forthcoming), the correlation between stature on the one hand and health and nutrition on the other is not straightforward. Potential height is to a large extent determined by genetic conditions, while many other elements in the relationship between the individual and his/her (anthropogenic or natural) environment govern the extent to which this potential is reached. Higher population densities and urbanization rates in the Roman world, for instance, could have resulted in more arable farming and less animal husbandry as more calories can be produced per land unit in the former strategy; consequently, a smaller intake of animal protein, though not necessarily of calories, could have reduced height (Koepeke and Baten, 2005, 65, 81).

The analysis of archaeological skeletal and dental remains seemed to confirm the expected commonness of malnourishment in the Roman world. Combining textual evidence with osteological indicators of nutritional deficiencies, Garnsey (1999, 51) concluded that the prevalence of malnutrition associated with the inadequate intake of specific vitamins and minerals could be regarded as established. Indeed, the occurrence of malnutrition need not be doubted, but the extent to which such deficiencies characterized the nutrition of ancient populations is a different matter. In the past decades, specialists in the field of paleo-osteology have warned historians not to jump to conclusions. Take for example iron-deficiency anaemia. Although it was realized that anaemia could be caused by both disease and diets deficient in iron, the frequency with which anaemia was observed in the skeletal remains seemed to confirm the hypothesis of widespread malnourishment

(Garnsey, 1999). More recently, however, it has been shown that the most commonly observed pathological condition in archaeological skeletal material used to attest iron-deficiency anaemia, porotic hyperostosis, besides dietary causes may follow from many other factors as well, such as parasites, genetic conditions, infectious disease and lead poisoning (cf. Walker et al., 2009). The latter cause may have been an even greater problem in the cities of the Roman world than in other early societies, due to the common use of lead pipes, though lead poisoning caused by poorly glazed earthenware, tin vessels, wine-making and general pollution was a common phenomenon in pre-modern societies (Waldron, 2006; McKinnon, 2007). Moreover, the frequency with which this condition is diagnosed shows great variability between sites, which may be related to lack of standardization, inter-observer differences (Killgrove, forthcoming), and – one may add – *a priori* assumptions. In short, porotic hyperostosis is only a weak indicator of inadequate iron intake.

The challenge for future research is not only to draw up more nuanced models of (mal)nutrition in the Roman world, but also to distinguish between groups of different age, gender and social position. Recent studies observe variation in stable isotope characteristics of human remains, indicating differences in diet, but these divergences allow for only very broad conclusions. Examples include determining trophic level, the balance between terrestrial and marine foodstuffs and attesting the consumption of different groups of cereals based on their photosynthesis pathways. Variation in dental health (the frequency of caries and calculus) may also elucidate differences in the composition of the diet of different groups. Some studies for instance suggest that men may have eaten more fish than women and had a diet that stimulated lesions, which possibly indicates a greater consumption of wine (Bourbou, forthcoming; Prowse, 2011). It remains difficult to assess as to what extent the patterns observable in one set of individuals may be generalized into wider conclusions regarding diet and nutrition in the Roman world (cf. Scheidel, 2012; 330). It is clear, however, that conclusions regarding nutrition in the ancient world cannot be made on the level of ‘the Roman Empire’, but need to take into account gender and age, and the role of geography, social and economic structures, settlement type, political status and cultural background. Hence, scholars should be careful not to generalize conclusions drawn on the basis of specific case studies.

This is not to argue that malnutrition did not affect significant segments of Roman society, but it is to warn against the *a priori* assumption that nutritional deficiency was the constant and inevitable fate of all but a happy few. Chronic deficiency must moreover be distinguished from temporary food shortages, and the latter were undoubtedly common in the Roman world. But once again, nuance and differentiation are necessary. The inhabitants of the political centres of the Roman world were shielded from famine by state interference most of the time (Erdkamp, 2005, 2015). It is often claimed that the logistical challenge of feeding large cities imposed a cereal dominated diet on their inhabitants, resulting in a one-sided and hence inadequate diet. On the one hand, cereals seem to have had a primary role in the urban food supply, as almost all measures regulating the food market in classical Athens and the Roman world are limited to cereals and bread. Furthermore, our written sources pay far more attention to the grain harvest and grain prices than any other foodstuff, while the distribution of subsidized or free food in the city of Rome was for three centuries limited to wheat (cf. Erdkamp, 2013). On the other hand, this should not rule out a significant consumption of other foodstuffs. While providing sufficient amounts of perishable items out of season, such as fresh vegetables and fruits, in the case of the metropolis Rome may indeed not have been possible, we believe the view of a diet overly dominated by cereals to be too grim, if only because wine, olive oil, garum and pulses were not logistically unattractive (cf. Corbier, 1999 on pulses). We will argue that especially the latter category is under-represented in most modern models. In contrast to urban dwellers, rural populations in more isolated inland areas were subjected to the vagaries

of the weather and could not count on external aid or exchange if famine broke out. Countering this risk was a central element to the economic and social functioning of such rural communities. If left unburdened by heavy rents and taxes, they generally aimed at producing above mere subsistence level, so as to build up a reserve for bad years (cf. Forbes, 1989; Halstead, 1989). Agricultural and social survival strategies thus alleviated individual crises, although they were not able to ward off hunger all the time (Garnsey, 1988; Gallant, 1991; Erdkamp, 2012). Every so often, they failed. The point is, however, that food availability in the countryside fluctuated heavily between good years and bad years – the proverbial times of feast and times of famine. Under such conditions, chronic hunger and malnutrition would have been limited to the very poor.

3. Modern malnutrition: the hazards of analogy

It is estimated that roughly between half and two-thirds of the modern world population suffers from at least one nutritional deficiency. Just as salient is that these deficiencies are not limited to the developing world, but are also common in developed countries (Stein, 2009; Miller and Welch, 2013a; Miller and Welch, 2013b). Of the world's population 15% suffers from energy malnutrition or undernourishment, which could be defined as 'classical hunger'. 'Hidden hunger', being deficient in one or more micronutrients, is even more common. According to WHO standards, roughly 15% of the world population is deficient in selenium, 33% is deficient in zinc, 35% is deficient in iodine and 30% of the population is deficient in iron to the point of anaemia, to name just a few examples (cf. Stein, 2009 for an overview of underlying studies). Some deficiencies are particularly prevalent among children: vitamin A deficiency for instance occurs in 33% of all children under age 5, with percentages reaching 50% in some parts of the world (WHO, 2009). Despite the obesity epidemic in high income countries, 'being underweight' is still the number one health risk factor for cause of death worldwide identified by the WHO, with 20% of all children under age 5 in developing countries being underweight. Even today, 12.7% of all deaths in low income countries are related to malnutrition (against a global average of 6.6%); being underweight being responsible for 7.8% of this total, suboptimal breastfeeding for 3.7%, vitamin A deficiency for 2.2%, zinc deficiency for 1.5% and iron deficiency for 0.7% (WHO, 2002, 2004, 2009 – folate, vitamin D, calcium and vitamin B₁₂ deficiencies were also recognized as major contributors, but their effects have not been quantified). Mortality, however, is not the only consequence of malnutrition; other dire consequences include reduced life-expectancy, stunted growth, reduced or delayed cognitive development (zinc and iron deficiency) and cataract blindness (vitamin A deficiency). To express the total burden of disease the WHO uses Disability-adjusted Life Years (DALY) as a summary measure that represents the (yearly) equivalent loss of a healthy year of life due to a risk factor. Here too, malnutrition is a factor of importance being responsible for 18.1% of all DALYs in poor countries; worldwide 33% of all DALYs incurred by children under age 5 are caused by malnutrition. In high income countries nutritional deficiencies tend to be less severe and only mildly affect mortality risks or DALYs – only 'low fruit and vegetable intake' making it into the top ten, being responsible for 2.5% of all deaths and 1.3% of DALYs (WHO, 2009). This does not mean that less severe malnutrition is uncommon nor that it does not lead to suboptimal outcomes. Furthermore, energetic over-nutrition may still coincide with micronutrient deficiencies, for instance, in an obese person with iron-deficiency anaemia.

The source of malnutrition does not always lie in the diet. The effect of diseases and parasites should not be underestimated in causing modern deficiencies. A common example is the intestinal parasite hookworm (*Ancylostoma duodenale* and *Necator americanus*). Hookworm infection is usually soil-transmitted (often through walking bare-foot over infected soil) and may quickly spread under unsanitary conditions; its spread is further aided by the agricultural use of human faeces as

manure (Crompton and Whitehead, 1993). Hookworms contribute significantly towards iron-deficiency anaemia, especially when they invest a host with a poor or moderate nutritional status in high concentrations. In 1990 over 900 million people (roughly a fifth of the world population) were infected with hookworms (Pawlowski et al., 1991) and in 2012, thanks to programs combatting hookworm infection, 500 million people (roughly a fourteenth of the world population) suffered from it (Fenwick, 2012). In areas where hookworm infection occurs, the prevalence of hookworms is close to 100% of the population (Schad et al., 1983). Unlike most intestinal worm infections that especially affect infants, hookworm infection is somewhat of an 'occupational' hazard for farmers (cf. McNeill, 1976). Especially in rural areas of the African, Mediterranean and Near Eastern parts of the Roman Empire, hookworm infection may well have been a factor of import in causing iron-deficiency anaemia.

The above data somewhat contextualize the presence of indicators of malnutrition in the past and the conclusions we can draw from them. Even in the postmodern era, varying degrees of malnutrition seem to be part of the 'human condition', and there are no indications that this will change in the near future. Despite a proper understanding of nutrition and the economic, medical and technological capabilities to prevent it, yearly many millions of deaths and DALYs are incurred in low-income countries from what the WHO describes as 'easy to remedy nutritional deficiencies' (WHO, 2009). Simultaneously deaths and DALYs incurred from (the consequences of) different forms of over-nutrition are common in high-income countries. This suggests that unequal distribution of wealth plays an important role in the persistence of malnutrition. Economic growth as a factor which may reduce malnutrition is generally deemed to be of lesser importance than the distribution of wealth by modern researchers, as economic progress does not automatically 'trickle down' to the poor (Haddad et al., 2003). More important perhaps is that households usually do not select foodstuffs based on micronutrient content, but on other attributes. Especially when consumers are unaware of their nutritional needs and the nutritional properties of foodstuffs – as we may assume was the case for Roman consumers – increases in income do not automatically lead to a more balanced diet or the reduction of malnutrition. There is a great body of case studies from the 20th and 21st centuries in which economic growth and the rise of real incomes in poor communities did not reduce micronutrient deficiency, even when cheap options to do so were available. Additional income was used to purchase more or even better food, but not necessarily food that aided resolving existing deficiencies (for an overview, see Stein, 2009). Nutritional ignorance therefore should be considered as a factor when modelling Roman malnutrition. Furthermore, increases in income may also be used towards consuming non-food items or prestigious foodstuffs with a negligible nutritional value such as pepper and other spices (cf. Heinrich and Hondelink, 2017 on quantifying Roman pepper consumption), or coffee and tea in more recent times. Researchers, for instance, have shown a positive correlation between tobacco consumption and childhood malnutrition and stature in households in developing countries. Children in non-smoking households were taller and had fewer deficiencies as a greater share of the income was devoted to food in such households than in smoking households with a similar income (Block and Webb, 2009). It is not unfeasible that the spending priorities of parents, for instance with respect to wine, could have caused similar effects in the Roman context. These priorities in themselves may also negatively affect nutritional status. Productivity and real income increases may for instance be used to produce and consume more alcoholic beverages, whereas the overconsumption or abuse of alcohol may in turn lead to micronutrient deficiencies and malnutrition, as we noted with respect to Roman dental health. Interesting in this context is a study by Willem Jongman (2007) who has argued that the population of Roman Italy derived a much greater percentage of their caloric intake in the form of wine and olive oil than previously assumed. Though the break with the view of a monotone cereal diet has much merit,

Jongman's metrics are somewhat off. While underestimating cereal yields, the average consumption rate of 100 l of wine per person per annum Jongman assumes in his model is more than exceptionally high as is indicated by comparisons with early modern Europe (Allen, 2009, 334). Furthermore, the 165 kcal per 100 ml he assumes for wine is in the range of port or very sweet alcoholic beverages and therefore well above likely estimates for ancient wines, in particular the cheaper kinds. The high wine consumption hypothesis is however interesting in the context of the phenomena listed above.

The smoking household example also brings to the fore the point that besides the inequality in the distribution of wealth within society, the income of the household is often unequally distributed over family members. As Garnsey (1999) noted, social hierarchy, not need, determined this distribution. This has not changed: (pregnant) women and infants are still overrepresented among the malnourished. Infants who survive malnourishment and associated ailments do incur DALYs and grow up to be adults setback for life, often suffering from mental, physical and subsequently economic consequences (WHO, 2015). This is an aspect of childhood malnutrition that is difficult to attest archaeologically: we may find the skeletons of children who perished from malnutrition, but the aggregate damage done over a lifetime by childhood malnutrition to those who survived to become adults remains largely invisible.

Besides the human cost, malnutrition has a significant economic cost in terms of lost productivity and economic growth (cf. Fogel, 2004). Deficiencies in iron, zinc, and vitamin A alone cause approximately a loss of 5% of the world's potential GDP, but in some countries this is as high as 11% (Haddad and Bouis, 1991; World Bank, 1994, cf. Lopez et al., 2006; Stein and Qaim, 2007). These losses spring from the reduced productivity of labour and the quality of 'human capital' through physical and cognitive disabilities or other suboptimal outcomes. Malnutrition and poverty therefore are factors in what is called the 'malnutrition poverty trap' in which poor nutrition causes lower productivity and lower income, in turn causing even poorer nutrition (Stein, 2006). Conversely, better nutrition increases productivity and income; for instance, models have indicated that the income of agricultural labourers in India could be raised by 5–17% by resolving their iron deficiency (Weinberger, 2003). These considerations are also relevant to national economies and economic history. Evidence regarding nutritional status and degree of malnutrition therefore could also be a useful variable in modelling the Roman productivity and the Roman economy's potential for economic growth.

4. The great divide: the Green Revolution and the anachronistic use of modern malnutrition

Despite the importance of cereals as staples and energy suppliers in the diet, their nutritional appraisal by economic historians, on average, has been far from positive. Often the main arguments against cereals as a positive contribution to the diet, beyond supplying energy, have been their (alleged) inherent micronutrient deficiencies and large concentrations of anti-nutrients. Peter Garnsey, for instance, in his *Food and Society in Classical Antiquity* (1999), implicitly painted the picture that the centrality of cereals in the ancient diet helped cause endemic, chronic malnutrition and a subsequent array of diseases (cf. Heinrich, in press-a). Invariably, historians who want to argue in favour of healthy Roman diets do so by stressing the high consumption of non-cereal foodstuffs, preferably meat and other sources of animal protein, rather than redeeming cereals (e.g. Jongman, 2007; Mylona, 2016; Kron, forthcoming; McKinnon, forthcoming).

While the consumption of sufficient (animal) protein and general dietary variety are quintessential to nutritional health, one might wonder whether that statement justifies a negative assessment of the nutritional and dietary role of cereals. A major problem in ascertaining this is that we possess no direct evidence as to the (micro)nutrient content of ancient cereals. Therefore, historians who wish to quantify

ancient cereal nutrition, use values obtained from the analysis of modern crops by cereal biochemists. Though such data are scientifically sound, they cannot be directly applied to the past due to several biases. Modern studies, for instance, mostly focus on the currently economically important subspecies bread wheat (*Triticum aestivum* ssp. *aestivum*). In antiquity, other wheat (sub)species and other cereals often played more important roles and their nutritional parameters are different (for a discussion and overview, see Heinrich, in press-a). Furthermore, the values of nutritional parameters in wheats and other cereals may vary significantly depending on factors such as genetics (with differences at any taxonomic level), soil conditions, seasonality and human interference (e.g. activities such as manuring or marling) and various others (Heinrich, in press-a). Advances in cereal biochemistry also force us to nuance some of the conventional wisdom regarding cereal nutrition as expressed by Garnsey (1999) and others. While, for instance, it is indeed true that vitamin A is absent in wheats, they do contain carotenoids. Carotenoids act as pro-vitamin A, meaning that the body can use them to synthesize vitamin A on its own (Ortiz-Monasterio et al., 2007). Hard wheat (*Triticum turgidum* ssp. *durum*), which was of great importance in most of the Mediterranean during the Roman Period (Heinrich, in press-b), can be particularly rich in carotenoids (Ortiz-Monasterio et al., 2007).

A much greater bias that springs from the use of modern biochemical data is that it implicitly assumes that past cereal cultivars were nutritionally identical, or at least very similar, to our own. It is true that the cereal taxa we use today are the same as those that were used by the Romans, and most societies before them since the dawn of the Neolithic Revolution. Cereal cultivars have changed profoundly however over the past two-and-a-half centuries, first with the British Agricultural Revolution and later with the advent of scientific agriculture and genetic crop modification. The moment of the great divide between 'traditional' and 'modern' cultivars is situated in the Green Revolution of the 1960s. Some of the key contributions to this development were made by Nobel laureate Norman Borlaug (1914–2009) during the 1940's and 1950's at the Cooperative Wheat Research Production Program in Mexico. There Borlaug developed various high yield, disease resistant, dwarf (bread) wheat cultivars that moreover were suitable for areas where wheat previously could not be grown because of photoperiodism. By 1960 Mexico's wheat production had increased six fold, making the country not only self-sufficient in wheat production, but even a wheat exporter whereas previously it had been a wheat importer. After this Borlaug continued his work in South Asia, doubling wheat production in Pakistan and almost doubling production in India between 1965 and 1970. After these successes, the use of Borlaug's wheat cultivars quickly spread throughout the world, replacing traditional cultivars. Borlaug has been credited with having saved billions of lives through averting the Malthusian population crises in the 20th century that Neo-Malthusian biologist Paul Ehrlich had famously predicted (Ehrlich, 1968). Borlaug himself described his achievements only as a 'temporary success in man's battle against hunger and deprivation' or as a 'breathing-space' he hoped would last 3 decades (Borlaug, 1970). He understood full well that population would again catch up, though continuous agricultural improvements since then have staved off disaster thus far (Borlaug, 2000a). Crucial to Borlaug's work had been the 'Norin 10' dwarfing genes, that had been developed by the Japanese in the 1930's and that under the American occupation of Japan following World War II had been made available to American researchers. Dwarfing allowed for a far greater application of nitrogen fertilization, as the shorter wheats did not suffer from 'lodging': tall wheat cultivars beyond a certain yield would become 'top-heavy' and hang over, making it difficult to harvest or even causing the grain to rot on the fields. When lodging was no longer a concern (and thus removed as a limiting factor in increasing wheat productivity), the benefits of the Haber-Bosch process of producing low cost nitrogen fertilizer from synthetic ammonia could be reaped to their fullest extent (Borlaug, 2000b).

Only much later cereal biochemists discovered that the advances of the Green Revolution had negatively affected the nutritional characteristics of the new wheat cultivars. Micronutrient content, especially in terms of trace elements ('minerals'), was significantly lower in modern cultivars than in their 19th century counterparts preserved in herbaria. These differences are significant: for important micronutrients such as iron, zinc, copper, selenium, magnesium and calcium differences of up to 30% have been noted (Welch and Graham, 2000; Garvin et al., 2006; Fan et al., 2008a, 2008b; Zhao et al., 2009; Shewry, 2009, cf. Heinrich, *in press-a*). The causes of these decreases are twofold. First, there is a dilution effect: the available micronutrients in the soil are divided over a greater number of wheat plants and grain kernels. This effect is especially strong in developing countries where many farmers cannot afford trace element biofortification to restore soil nutrient levels. The second cause is that the Norin 10 genes, responsible for dwarfing, inadvertently reduced the cultivars' ability to route trace elements to their kernels (Shewry, 2009). Improved productivity came at the cost of losses in nutritional quality. Had population not increased, the reduction of micronutrient content would only have had limited effects: doubling or quadrupling output would have increased the amount of grain available per capita sufficiently to offset the loss of a third of the micronutrient content per weight unit. Population, however, did not stay constant and has roughly doubled since the development of the high yield cultivars. Therefore the consumer who can now afford to purchase an x amount of wheat, will in terms of micronutrients be roughly 30% worse off than a consumer who could afford the same amount a century ago. Especially the poor in the developing world, who are greatly dependent on cereal staples, suffer malnutrition effects caused by this development. Industrial pollution may also affect cereal micronutrient content, especially in the case of the micronutrient selenium, of which the uptake by plants can be hindered by sulphur. Large emissions of sulphur dioxide (SO₂) between the 1920s and 1970s resulted in substantially lower selenium contents in cereal specimens from this period, with cereal selenium content returning to pre-1920s levels by the early 2000s after SO₂ pollution had been drastically reduced (Fan et al., 2008b).

While we cannot assume that Roman or other historical wheat cultivars had nutritional characteristics identical to those of the 19th century and other pre-Green Revolution cultivars in the studies cited above, it is apparent that the effects responsible for the modern decrease in micronutrient content do not apply, if only because the Romans never developed genetically modified dwarf cultivars. Moreover, micronutrient dilution due to high yields could not have occurred to the extent witnessed in modern high yield cultivars. It would therefore be anachronistic to fully equate the modern relationship between wheat micronutrient content and malnutrition with that relationship in the Roman world.

The Green Revolution had another effect: it greatly increased the proportion of cereals in the diet in developing countries. Prior to the Green Revolution, pulses were an important component of the diet in many societies. With the dramatic improvements in wheat yields, however, many farmers reduced or stopped the cultivation of pulses, which now comparatively lagged behind in productivity. Even in countries where pulses were an appreciated food item, such as India, production decreased. There, while the population rose by 50%, the production of pulses decreased by 20% (Akroyd et al., 1982). While high yield pulse cultivars were developed in the decades after the initial stage of the Green Revolution, the consumption of pulses has continued to decrease. This has been much to the alarm of nutritionists and the FAO; the latter, in order to raise awareness about the detrimental nutritional consequences of this development, declared 2016 the year of pulses (Pastor-Cavada et al., 2014; FAO, 2013). Because of this development, the high proportion of cereals in the diet of modern low-income populations and the negative nutritional effects that follow from it, cannot necessarily be projected on the Roman context. It is far more feasible that the majority of the Roman population enjoyed a diet that,

though heavy on staples, was comprised of a more diverse and balanced combination of different cereals and pulses with complementary nutritional profiles. The inadvertent or purposeful mixing of different cereals and pulses, for instance, during harvesting and processing or within a single dish or as part of the daily meal was moreover a well attested practice in most sub-recent and pre-modern societies, including Roman society, though it has now largely disappeared in most places (see Hansen and Heinrich, *in press* for a discussion). The same consideration applies to various traditional food processing and food preparation methods, in particular fermentation, which may ameliorate the nutritional profile of cereals by increasing and diversifying the available nutrients or by neutralizing anti-nutrients such as phytate (Campbell-Platt, 1994, cf. Hansen and Heinrich, *in press*).

5. Conclusion

In this paper we have reflected on the potential pitfalls of using insights and data regarding modern malnutrition in estimating Roman malnutrition. We have emphasized that malnutrition is still common today and rather a part of the human condition than a purely or primarily historical phenomenon. Economic growth in itself, as we have seen from modern examples, has only a limited effect in countering malnutrition; nutritional ignorance or even consciously made unhealthy choices, spending priorities and the unequal distribution of foodstuffs, both within the household and society at large, are at least as important as determinants. From the first of these observations, it follows that we may expect to commonly find indications for malnutrition for the Roman period, but that the macroeconomic explicative capacity of such indications is limited. From the second observation it follows that indications of malnutrition are neither an argument against Roman economic growth, nor for the inevitability of a Malthusian scenario. In fact, it has been argued that for a long time, the Roman world saw both population growth and an increase in average living standards (Erdkamp, 2016). This in itself would be an argument against a poor Roman nutritional status: nutritional status is a co-determinant of economic growth as it affects labour productivity and the quality of the human capital. Considering its modern economic cost or gains and place in potentially virtuous and vicious cycles (the poverty-nutrition trap) we believe this aspect is important in modelling Roman economic growth.

That malnutrition is also a modern phenomenon however does not mean that its nature and causes are the same for antiquity and modernity. In fact, we have argued that the causes and nature of Roman and modern malnutrition are categorically different. The relationship between modern micronutrient deficiencies and cereal consumption has its origin in the Green Revolution of the mid-20th century, due to a combination of trace element dilution as a consequence of dramatic yield increases and the inadvertent, and long unnoticed, side effects of genetic manipulation that cause decreased routing of minerals to the grain kernels of new cultivars. This effect was amplified by the increased centrality of cereals in the diet as farmers shifted towards cultivating cereals over now markedly less productive crops such as pulses. In turn, this led to staple foods becoming more homogenous and nutritionally less complementary. Simultaneously with these developments, several traditional food preparation methods with beneficial nutritional effects became less prominent as they were replaced by modern practices. The dietary role and nutritional profiles of Roman cereals could not have been affected by these developments and arguably Roman cereals may have been both more nutritious as well as less of a monolithic dietary element. Therefore, we note that with respect to cereal nutrition or malnutrition the distinction between 'modern' and 'pre-modern' agricultural regimes is less relevant than that between pre- and post-Green Revolution regimes. In conclusion, we should be cautious to neither overemphasize the role of cereals in reconstructing the diet in the Roman world nor to appraise their nutritional values too pessimistically. We should strive to separate the chaff from the wheat in our use of modern data.

Conflicts of interest

The authors declare that they have no conflict of interest.

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