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Trade and dietary preferences can determine micronutrient security in the United Kingdom

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Food production, dietary choices, climate change, trade tariffs and future responses to the SARS-CoV-2 pandemic are some of the factors affecting global food security. Here we examine how micronutrient security has varied in the United Kingdom from 1961 to 2017, before Brexit, taking supply and demand driver changes into account. We also introduce future scenarios to see how a more plant-based diet and/or differing trade arrangement post-European Union exit and COVID-19 pandemic could affect the supply of nutrients. Results show that trading agreements have affected several key micronutrients during the past 60 years and are likely to be influential in a post-Brexit United Kingdom. Changes in dietary patterns influence how much animal- and plant-based products have also affected micronutrient security and are likely to do so in the future with increased interest in consuming a more plant-based diet.

The past few years have seen major disruptive challenges, not least from the COVID-19 pandemic, for food systems; the disease has exposed inequalities in health, economic and environmental settings[1,2]. Interestingly, there has been a clear link in the pandemic with dietary NCDs (obesity and diabetes)[3]. The importance of nutrition in forming a robust immune system, which can affect SARS-CoV-2 infection outcomes, is gaining attention, including a prospective study assessing risk and severity of COVID-19 infection when healthy plant food diets were associated with lower risk and severity of the virus[4–6]. Micronutrient deficiencies are common yet often overlooked in many discussions on food security, where focus has been solely, for too long, on calories[7]. Socio-economic inequality affects availability and access to micronutrients[1], while also influencing the double burden of malnutrition[8].

Increasing awareness of the role food systems play in climate change has resulted in many researchers calling for a change in diet; for example, those involved with the EAT–*Lancet* Commission[9] proposed a planetary diet based on sustainability and health, although the Eat–*Lancet* reference diet did not suggest examples of national diets. The EAT–*Lancet* Commission increased awareness with some researchers estimating the cost of an 'EAT–*Lancet* diet' exceeds household per capita income for at least 1.58 billion people[10]. Relative poverty therefore renders environmentally sustainable diets such as EAT–*Lancet* unaffordable to more than 20% of the world's population. However, recent modelling by Springman[11] and colleagues estimates the costs of healthy and sustainable diets in high-income and upper-middle-income countries: dietary change interventions that incentivize adoption of healthy and sustainable diets can help consumers in those countries reduce costs while, at the same time, contribute to fulfilling national climate change commitments and reducing public health spending[11]. An article in *Nature*[12] highlights the continuing debate about the EAT–*Lancet* diet and its sustainability/affordability and that the Food and Agriculture Organization of the United Nations (FAO) will convene a group to reconsider such a diet with results to be published in 2024. Further context has been provided by the UK government-commissioned National Food Strategy, calling for a change to the UK food system, which outlines four outcomes required for improved human and planetary health[13].

The United Kingdom's decision to leave the European Union and the EU Customs Union (EUCU) and European Single Market (ESM) has raised many questions about food security and the role of trade and self-sufficiency provided from domestic supply for the UK food system[14]. We have examined the UK food system as a case study of global relevance. Our analysis focuses on five of the seven key micronutrients (namely vitamin A, vitamin C, iron, calcium and zinc) flagged by previous studies[4,14] as weaknesses in the UK's nutrient security between 2015–2017 (2016r) using FAO[15] data. The five micronutrients chosen as the focus in our study are the least secure and most relevant to our focus on plant-based, specifically fruit and vegetable, diets and/or are most affected by current—and therefore, likely, future—trading relationships. This allows us to compare with a recent audit of the UK's nutritional security (2009–2011 (described as 2010r in our work)) and extended analysis using datasets going back to 1961[16].

In addition, we analyse the 2017 overseas trade data from HM Revenue & Customs (HMRC) to assess the United Kingdom's overseas food supply before its exit from the EU/EUCU/ESM. Using analysis of domestic/imported supplies, we offer insights on what micronutrient challenges need addressing to meet our ever-changing demands. The United Kingdom's domestic contribution to fruit and vegetable supply decreased by half (between 1987 to 2013)[17], and the total amount of fruit and vegetables consumed by the UK population constituted only 26% of what is the recommended Eatwell plate portion[18].

The COVID-19 pandemic highlighted global concerns regarding long and complex supply chains and food insecurity among the vulnerable[1]. The ambition of 'building back better'[19] will require the United Kingdom to explore how best to recover from the COVID-19 pandemic while also building and developing new global trade arrangements. Leaving the EUCU and ESM in January 2021 did lead to significant disruption in UK trade[20], and while this might be temporary as trade did start to rise again[20], it may indicate a more long-lasting and developing situation from the pre-COVID-19 and pre-European Union exit period. A pandemic occurring in the United Kingdom at the same time as leaving the European Union creates a whole new 'challenge' or 'opportunity' for food security. This case study is of wider relevance as many countries consider their global reliance and future systems they want to build back

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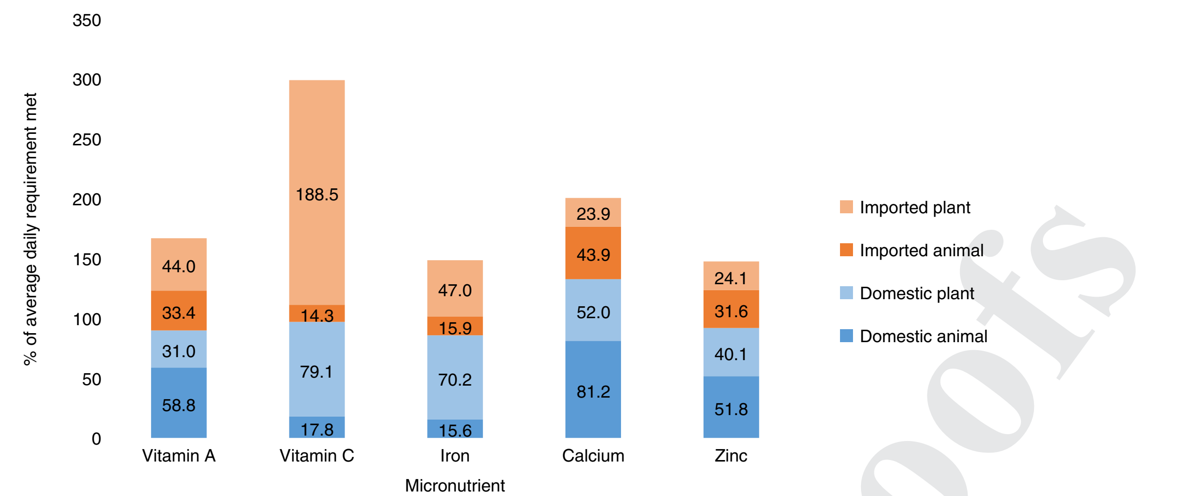

Fig. 1 | Sources of micronutrients in 2016r. Micronutrients supplied from domestic animal and imported animal supplies and domestic plant and imported plant supplies are presented as a percentage of the recommended UK population-level intake in 2016r.

post-COVID and alongside the continuing push for changes in diet and/or the food system[9,21,22].

Using a scenario analysis approach[23,24], we explore two uncertainty axes of importance to food security and food system transformation[9,25–27], that is, domestic/import and animal source foods/plant-based foods. The focus on two uncertainties has been used in scenario analysis of the future of the UK food system[24] and by international studies looking at future food systems[23]. Here we introduce a scenario analysis approach that allows consideration of the state of the United Kingdom's food system on leaving the European Union and how future scenarios might emerge to manage pressing challenges with climate change, sustainability and a globalized food system. We also analyse where the United Kingdom was positioned using a series of plots during the past 60 years, which shows how micronutrient security has changed and is therefore likely to change in the future as new trading deals and dietary preferences emerge.

Results

Micronutrient security in 2016r. Nutrient security has remained stable and secure between the most recent assessment in 2010r and 2016r (Fig. 1) and over the past 60 years (Fig. 2). While the domestic UK food supply has maintained or slightly increased its self-sufficiency for the vitamins and minerals studied between 2010r and 2016r, both vitamin A and vitamin C are less supplied domestically than the time points from the 1960s through 1990 (vitamin C) and 2000 (vitamin A) when we became less self-sufficient. We measure self-sufficiency as domestic supply of a micronutrient (production minus exports) relative to the population's requirements based on RNI, expressed as the percentage of the United Kingdom's population level's micronutrient requirement. Therefore, a self-sufficiency value of 100% means that the domestic supply (production minus exports) meets the nutrient requirements for the entire UK population to meet the RNI. This then allows us to align our 2016r findings with the values presented in Macdiarmid et al[16]. In Fig. 2 and Extended Data Fig. 1, we present a series of comparisons back to 1961, which illustrates changing trade (joining the European Union and so on) and changing diets. This self-sufficiency measure gives us an indication of how much of the United Kingdom's micronutrient needs can be provided by domestic supply. Although it is possible to imagine a scenario where exported food is redirected to domestic use, for contemporary analysis, exports are treated as a loss to self-sufficiency because we view consumption habits as inelastic except for in extreme conditions (for example, our previous analysis of meat supplies[28] identifies those components of exports were often cuts of meat not widely consumed in the United Kingdom, such as pig trotters). This means that between Macdiarmid's detailed analysis of 2010r, including datasets back to 1961, and our analysis of 2016r, the main factors changing self-sufficiency are (1) domestic production, (2) exports and (3) population growth, all of which our analysis explores.

Figure 1 illustrates the micronutrient security from both domestically produced and imported commodities in 2016r. All the minerals and vitamins are secure when considering both domestic and imported supplies. However, the supply represents the micronutrients supplied by the commodities and not the nutrient available to everyone, which is affected by an individual's diet, bioavailability of the nutrients and other factors that might mean the 'supply' figure is an overestimate of the actual micronutrient security provided to consumers in the United Kingdom. We are taking a macroanalysis approach and the fact that micronutrient security is at least 150% for all of these means any of the losses between supply and micronutrient availability in a person's blood are unlikely to be significant enough to take the value below what RNI delivers. For example, even if there were a difference of 30% between micronutrient supply and the amount available in the population's blood (after all losses in supply chain and bioavailability, once consumed), the United Kingdom is secure in all micronutrients studied, although individuals with different dietary options and or accessibility/availability issues may well have micronutrient insecurities.

Domestic production/self-sufficiency of vitamin A, vitamin C and mineral micronutrients. The self-sufficiency of vitamin A in the 2016r period is 89.8% compared with 88% in the most recent previous assessment in 2010r. There was a 15.1% increase in domestic production of vitamin A since 2010r. However, exports have risen by 43.8%. Many of the food categories contributing to the growth in domestic production saw growth in exports as well, implying that most domestic production gains were exported abroad.

Self-sufficiency of vitamin C has decreased from 101% in 2010r to 96.9% in 2016r. Underpinning this was a decrease in domestic production of around 4.6%. The main contributor to this is the reduction of potato production. Exports of vitamin C have fallen by 6.5%.

For iron, the United Kingdom is 85.7% self-sufficient in 2016r compared with 80% in 2010r. This is caused by domestic production having increased by 1% and exports decreased by 14%, particularly exported wheat and products. The main plant-based contributor of

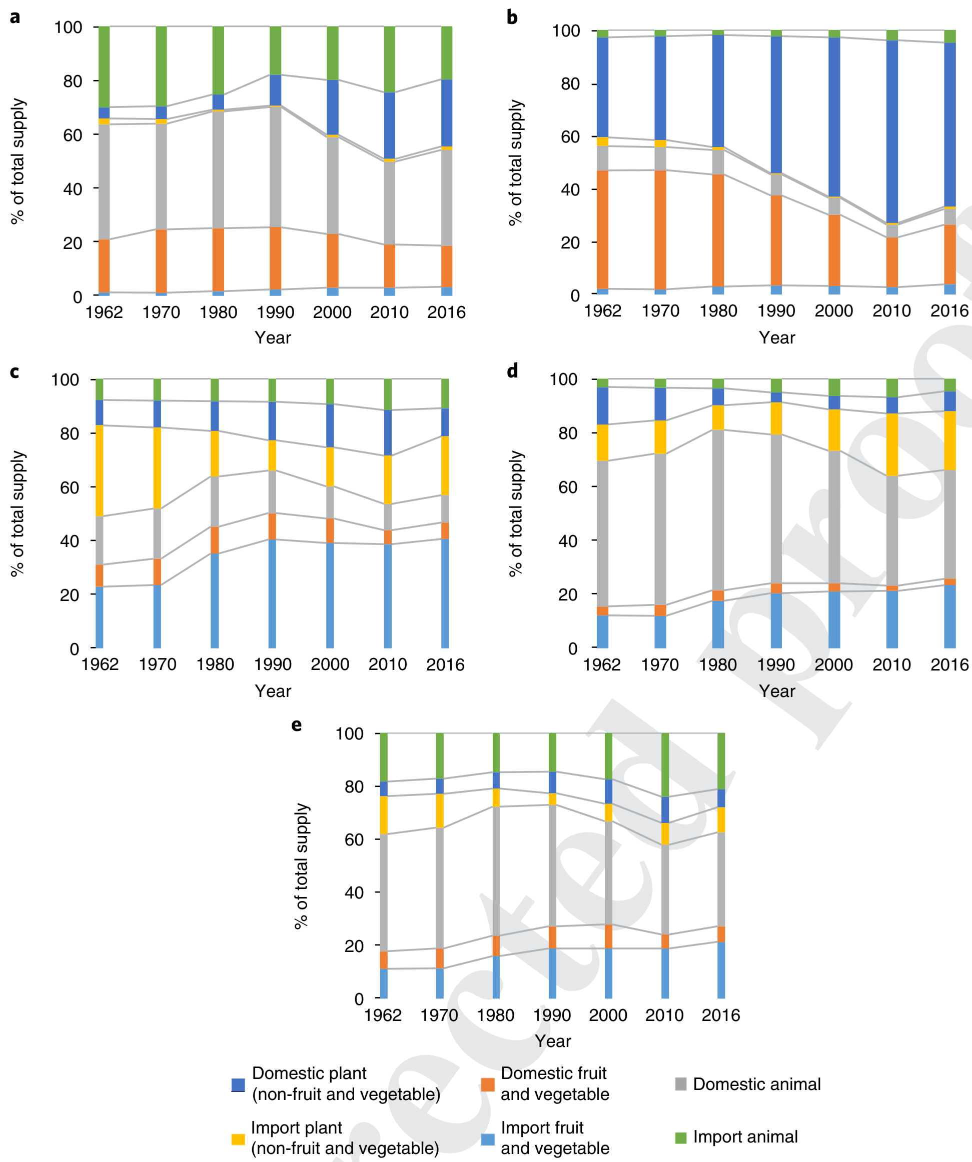

Fig. 2 | Sources of micronutrients from 1961 to 2017. Percentages represent domestic and imported sources of plants and animals during 1961–2017. These are represented in rolling averages, that is, 1962 is 1961–1963 and 1970 is 1969–1971 and so on. **a**–**e**, Each panel shows a micronutrient, as follows: vitamin A (**a**), vitamin C (**b**), iron (**c**), calcium (**d**) and zinc (**e**). The earliest year is presented in the graphs is 1961 in 1962r.

iron supply are cereals such as oats and wheat because of the fortification of these in products such as breakfast cereals[29] (https://www.activeiron.com/blog/cereals-high-in-iron/); 47.3% of the plant-based iron supply comes from wheat and wheat products.

For calcium, the United Kingdom is 133.1% self-sufficient in 2016r compared with 133% in 2010r. Underlying this result, domestic production has increased by 1.9%, whereas exports have risen by 8.8% due to the increase in exportation of milk and oats.

For zinc, the United Kingdom is 91.9% self-sufficient in 2016r compared with 84% in 2010r. This is a result of domestic production having increased by 7.5%. The main contributor to this increase is milk. However, exports have risen by 1.5% due to the increase in exportation of milk. The production gains manage to surpass population and export growth, resulting in the United Kingdom being more self-sufficient in 2016r than in 2010r.

Figure 1 combines the source of origin (plant-based and animal) and the domestic/import percentage of recommended population-level intake requirements. Plant-based supply is the majority source for vitamins A and C and iron and the minority for calcium and zinc. Plant-based supply of vitamin A is not secure (75%), and only 31% from the UK domestic supply of plants (self-sufficiency). In contrast, vitamin C from plants is comfortably secure (267.6%) but only 79.1% from just-UK domestic supply of plants. Iron is 70.2% from domestic plant and 117.2% from plant supply in total. The minerals calcium and zinc are more insecure when considering a prospective increase in reliance on plant-based supply. Calcium is 52% domestic and 75.9% in total, and Zinc is 40.1% domestic and 64.2% in total, both being insecure without major changes in plant-based supply should plant-based diets increase in overall dietary patterns.

Micronutrient security from domestic/imported sources of plant/animal origin. The increasing trend towards plant-based diets as recommended by EAT–*Lancet*[9] and an ever-increasing number of papers[30,31] highlights a need to consider the significance that plant-based micronutrients currently play and whether reductions in animal-based products create insecurity at the macroscale, which needs addressing.

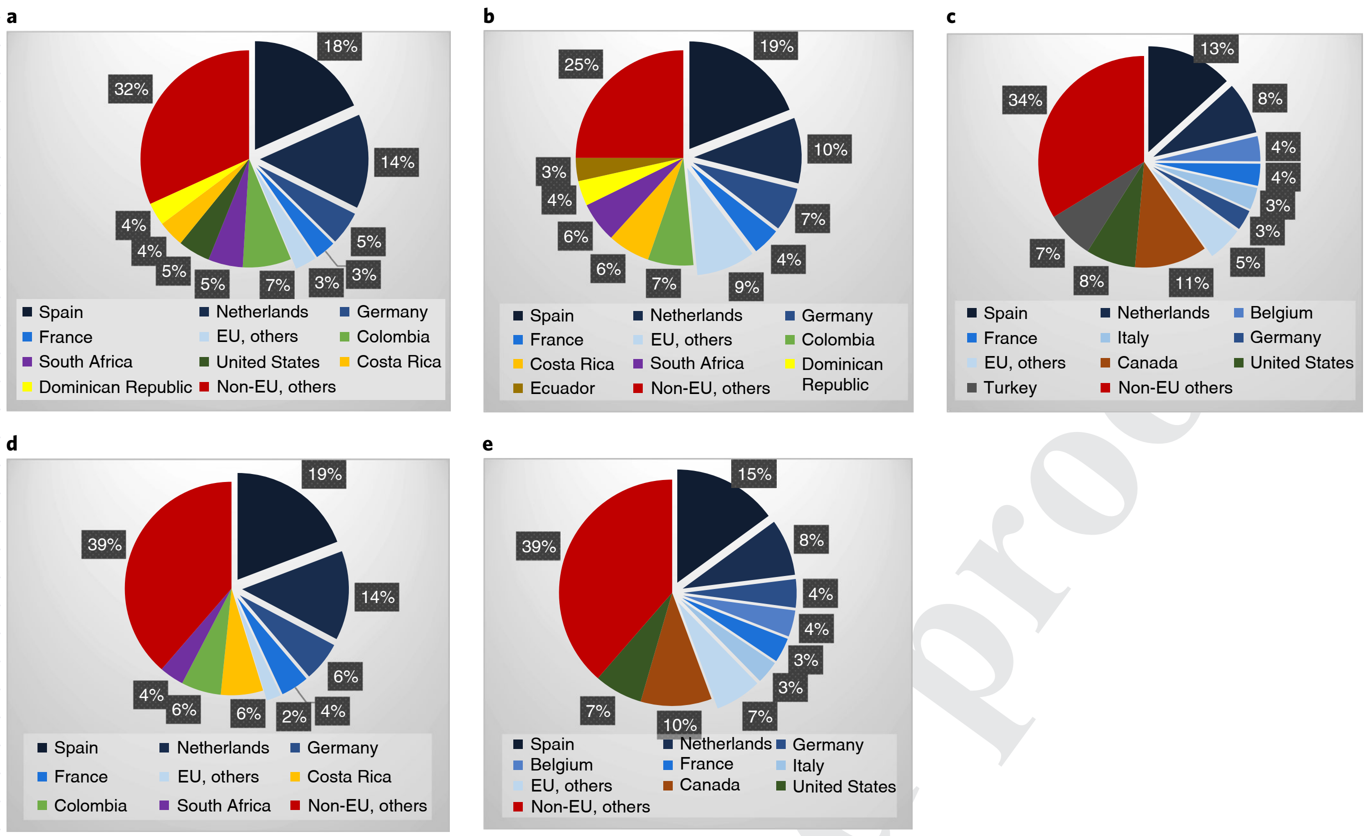

Fig. 3 | Country of origin of micronutrients from imported fruits and vegetables. These are expressed as percentages of total imported supply of fruits and vegetables. Countries within the European Union are represented on the right-hand side of the chart (in shades of blue). **a–e**, Each panel show a different micronutrient: vitamin A (**a**), vitamin C (**b**), iron (**c**), calcium (**d**) and zinc (**e**).

Figure 2a–e (and Supplementary Data 1) illustrates the percentage of the micronutrient supply (import and domestic) from commodities of animal or plant origin for the United Kingdom in periods back to 1961 based on weights. The plant-based commodities are further separated into the fruit and vegetable components.

Vitamin A (Fig. 2a) sees a move from animals to plants with an increase from 1962r (27.4%) through to 1990r (37.4%) and consistent since 2000r (44.1%) to 2016r (44.8%). Over time, vitamin C (Fig. 2b) has been fairly stable with a slight dip back to 1962r level (87.9%) in 2016r (89.3%) after reaching a high of 91.4% in 2010r. Data back to 1961 illustrate a change from domestic (1962r, 56.1%) plant-based supply of vitamin C to imported plant-based supply (26.4%, 2010r and 32.2%, 2016r), aligned with consumer changes in preference of fruit and vegetables.

With iron supply (Fig. 2c), there is a slight upward trend from plants that was quite constant from 1962r (74.1%) to 1980r (73.1%) and then increased to 78.7% in 2016r. For calcium (Fig. 2d), this level shows a slight upward move from 1962r (32.5%) to 2016r (37.8%); however, most of the supply is from animal sources. There is a similar slight upward trend for zinc (Fig. 2e) from plants that was quite stable from 1962r (37.7%) to 1980r (36.7%) before increasing to 43.5% in 2016r. However, the proportion from the fruit and vegetable components has fallen to an all-time low in 2016r of 11.9% after the proportion had peaked in 2010r (18.4%).

Currently, there is a move to vegetarianism/flexitarianism/veganism, and these supply figures seem to show this trend, albeit as small changes. Analysing data back to 1961 (Fig. 2 and Supplementary Data 1) shows movement towards plants but not as large a change as that away from domestic production. This is not surprising as the number of people adopting these diets is still small at a population level, and thus, while visible at the macroscale, it will be interesting to see how future scenarios will drive these changes more rapidly and significantly (Methods).

Sources and country of origin of United Kingdom-imported micronutrients from fruit and vegetables. As fruits and vegetables are a major contributor to the micronutrient supply in the United Kingdom and affected by trade and changes in consumer preference, we have undertaken more granular analysis of the imported fruit and vegetable component of the plant-based products that come from a range of countries. Since the United Kingdom has left EU membership, the United Kingdom is developing a new set of trading relationships alongside changes being driven by consumer dietary preferences, meaning such analysis will become increasingly important. We determined the fruit and vegetable imports from countries and crops using HMRC data from 2017. We were able to determine both country of origin and commodity type. Figure 3 illustrates the percentage of micronutrient supplies that come from fruit and vegetable-based imports just before the United Kingdom's decision to leave the European Union, and we have highlighted the European Union as a group of 27 in the figures.

Of the 27 member states of the European Union, Spain and the Netherlands are the major exporters of commodities supplying the micronutrients in the United Kingdom. We are able to calculate the percentage contribution of micronutrients as percentage population-level requirement from countries within the European Union by multiplying the percentage fruit- and vegetable-based imports from Fig. 1 and the percentage coming from these countries found in Fig. 3.

For example, fruit- and vegetable-based imports from the European Union contributed 43.7% of the imported fruit- and

Table 1 | Top 10 fruit/vegetable commodities imported to the United Kingdom for micronutrients vitamin A and C

	Vitamin A			Vitamin C		
Top 10 sources	Product	kg	%	Product	kg	%
1	bananas[a]	1,967	20.54	bananas[a]	737,598	23.76
2	tomatoes[b]	1,239	12.93	apples[c]	378,110	12.18
3	oranges[c]	1,179	12.31	sweet oranges[c]	322,780	10.40
4	apples[c]	662	6.91	tomatoes[b]	147,369	4.75
5	sweet peppers[b]	586	6.12	onions[b]	140,488	4.53
6	sweet potatoes[e]	465	4.86	cauliflower/broccoli[b]	105,954	3.41
7	onions[b]	354	3.70	watermelon[d]	96,942	3.12
8	guava/mango[a]	298	3.11	grapes[c]	78,400	2.53
9	pumpkin/gourd[d]	185	1.93	pineapples[a]	67,394	2.17
10	plantain[d]	180	1.88	pears[c]	66,459	2.14

These are expressed in mass of the micronutrient and the % that represents plant-based imports (supply) of that micronutrient. Shading represents the Food Foundation 5 categories: Hardy Heroes (not present in top 10); [a] Channel Hoppers; [b] Brexit Boosters; [c] EU Emigrants; [d] Globe Trotters. Commodities in grey are not listed in Food Foundation categories but are Globe Trotters. [e] Potatoes are classified nutritionally as a carbohydrate.

vegetable-based vitamin A supply (Fig. 3a). This EU fruit and vegetable contribution can be converted into the percentage of the United Kingdom's population-level requirement coming from a European Union-originating fruit and vegetable supply (meaning 43.7%, EU fruit and vegetable imports) of 95.3% (fruits and vegetables as % of plant-based) of the 44% from total imported plants. This represents 18.3% of the UK population's vitamin A requirement, where the total supply from domestic (minus exports) and imported animal and plant commodities in total provides 167.1% of vitamin A.

Using this method for the other micronutrients, we calculate that fruit and vegetable imports from the European Union contributed 90% of the UK population's vitamin C requirement, where the total supply provides 299.7% of vitamin C. Our analysis of data back to 1961 (Fig. 2 and Extended Data Fig. 2 and Supplementary Data 1) illustrates a fall in domestic plant production of vitamin C from 56.1% of supply in 1962r down to 26.4% in 2010r and 32.2% in 2016r. Fruit and vegetable imports from the European Union contributed 6.2% of the UK population's iron requirement, where the total supply provides 148.6% of iron.

Fruit and vegetable imports from the European Union contributed 4.2% of the UK population's calcium requirement, where the total supply provides 200.9% of calcium. Calcium will also be supplied from drinking water, which is not covered in our analysis.

Fruit and vegetable imports from the European Union contributed 4.4% of the UK population's zinc requirement, where the total supply provides 147.6% of zinc.

Tables 1–3 illustrate the top ten fruit/vegetable commodities imported to the United Kingdom for each vitamin (Table 1) and mineral (Table 2) in our study. For example, imported bananas supply 20.5% of the fruit- and vegetable-based supply of imports of vitamin A and 23.8% of the vitamin C. Using the figures presented in Fig. 3 derived from FAO FBS[32], we can convert these figures to what percentage of the United Kingdom's micronutrient requirement is supplied by bananas by multiplying the percentage of supply from Table 1 by the percentage of population-level requirement coming from fruit- and vegetable-based imports in Fig. 1. Imported bananas provide (20.5 × 95.3 × 44%) 8.6% of vitamin A for the United Kingdom and (23.8 × 98.5 × 188.5%) 44.2% of vitamin C. In the case of vitamin C, imported bananas provide 44.2% of a vitamin for which we are 299.7% secure (Fig. 1), compared with 8.6% of vitamin A for which we are only 167.1% secure (Fig. 1), dropping to 74.9% secure when looking at plant-based supplies (that is, excluding all animal source supplies) (Fig. 1). This is not because bananas are particularly nutrient-rich in these micronutrients but more because of the sheer mass of bananas that are imported into the United Kingdom.

In Tables 1–3, we have used a shading code to highlight the five Food Foundation Farming for 5-A-Day categories[14]. The coding system illustrates where commodities might be sourced and how self-sufficiency might be possible, or which new trading relationships will be required if there is a need to divert supply chains away from the European Union. It also highlights the need for consideration of how consumers change their dietary preferences/demand as has occurred over the past few decades[17] and is recommended in EAT–*Lancet*[9] and other publications[30,31].

Scenario development. Using the two uncertainties of what proportion of plant- versus meat-based supply of micronutrients will be in our future diets and the amount from domestic versus imported supplies allows us to establish the current position in 2016r, just before the decision to exit the European Union. These uncertainties are appropriate as they represent variables our analysis shows as seen in Figs. 2a–e and Extended Data Fig. 2 where we plot the 'baseline' at a series of date points over the past 60 years. This extended analysis back in time to the 1960s through to 2016r includes when the United Kingdom joined the European Union and our increasing focus on the role of animal-based versus plant-based supply of nutrients in our diet. When comparing the baseline in 2016r with data going back to 1961 (Extended Data Fig. 2), one can observe changes in the domestic/imported supplies, largely indicating a move towards imports for most of the micronutrients we analysed. Figure 4 illustrates the current position on these two axes for each micronutrient, within the context of the four possible future scenarios—namely: (1) self-sufficient plant source-rich diets, (2) global trading plant source-rich diets, (3) self-sufficient animal source-rich diets and (4) global trading animal source-rich diets.

The current position in 2016r for each micronutrient illustrates where we sit in each scenario and thus movement in any direction, as illustrated in Fig. 4 by the movement to the top left (EAT–*Lancet* planetary diet and increased domestic supply), will have differential effects on each micronutrient in terms of how a change in demand or supply will affect the security and not always in the same direction. This illustrates that change may affect each micronutrient differently and the ability to secure one nutrient through trading polices and/or changing dietary preferences may not be sufficient for other nutrients. Extended Data Fig. 2 illustrates how over the past 60 years, the position within the two axes has changed, highlighting that these vari-

Table 2 | Top 10 fruit/vegetable commodities imported to the United Kingdom for mineral micronutrients iron, calcium and zinc

	Iron			Calcium			Zinc		
Top 10 sources	Product	kg	%	Product	kg	%	Product	kg	%
1	dried kidney beans[c]	417,623	11.73	bananas[a]	2,243,529	17.13	dried kidney beans[c]	46,749	10.61
2	dried chickpeas[c]	218,391	6.13	apples[d]	1,286,624	9.83	bananas[a]	30,733	6.97
3	bananas[a]	194,644	5.47	tomatoes[b]	1,250,643	9.55	dried chickpeas[c]	25,394	5.76
4	sultanas[c]	137,394	3.86	sweet peppers[b]	572,539	4.37	cashew nuts[c]	16,487	3.74
5	dried lentils[c]	11,4425	3.21	melons[a]	535,861	4.09	potatoes[e]	14,478	3.29
6	tomatoes[b]	103,556	2.91	onions[b]	516,995	3.95	mushrooms (agaricus)[b]	13,729	3.12
7	sweet potatoes[a]	103,073	2.90	potatoes[e]	468,135	3.57	dried lentils[c]	13,508	3.07
8	dried grapes[d]	98,976	2.78	pineapples[a]	451,538	3.45	dried peas[d]	12,536	2.85
9	sweet peppers[b]	90,195	2.53	pears[c]	356,219	2.72	sweet potatoes[a]	12,225	2.84
10	onions[b]	89,912	2.54	avocado[a]	329,773	2.52	cauliflower/broccoli[b]	11,949	2.77

These are expressed in mass of the micronutrient and the % that represents plant-based imports (supply) of that micronutrient. Shading represents the Food Foundation 5 categories: Hardy Heroes (not present in top 10); [a] Channel Hoppers; [b] Brexit Boosters; [c] EU Emigrants; [d] Globe Trotters. Commodities in grey are not listed in Food Foundation categories but are Globe Trotters. [e] Potatoes are classified nutritionally as a carbohydrate.

ables do change over time and that the decision to leave the European Union is likely to cause changes in the way that analysing data from the 1970s onwards shows the historical changes observed when the United Kingdom joined the European Union (Extended Data Fig. 1).

Discussion

Integration of trade and production data have been integrated in previous studies[28,33], but we offer novel integration of trade and production databases, including the use of a HMRC database to determine the nutritional security of several key micronutrients just before the United Kingdom's decision to exit the European Union. Our analysis identified that the United Kingdom had maintained its self-sufficiency, between the most recent assessment in 2010r and 2016r, for vitamin A, calcium, zinc and iron but the self-sufficiency had dropped for vitamin C (now 96.9%). Our comparison with data going back to 1961 (Fig. 2 and Extended Data Figs. 1 and 2) shows how changes in production and trade have changed over the past 60 years, which is of interest in showing the situation pre- and post-decision to join the European Union in 1973. Extended Data Fig. 1 shows significant changes in import/domestic supplies, including increased export of domestically produced products. Using the HMRC database, we were able to determine the reliance of plant-based imports from the European Union, with a specific focus on fruits and vegetables, and which commodities were the most important from a plant-based origin, in line with increasing environmental and dietary recommendations to increase plant-based diets[9,30,31]. Combining supply and demand data, we showed the importance of commodities such as bananas in providing 8.6% of the population-level requirement for vitamin A, of which we are 167.1% secure. Early statistics on trade with EU member states[20] have already shown significant changes, which might become resolved as discussions and agreements on standards and inspections continue, but it illustrates early signs of major change from business as usual. Looking at the trade pattern in the 1970s and 1980s shows how the decision to join the European Union affected micronutrient supply and security, resulting in significant changes in imports and exports (Extended Data Figs. 1 and 2). Leaving the European Union, coupled with the shocks associated with COVID-19, suggest we might see similar, if not significantly larger, changes moving forward, especially when coupled with changing consumer diets and preferences and the agreements made at the UN Climate Change Conference in Glasgow (COP 26; https://ukcop26.org/the-conference/cop26-outcomes/).

Table 3 | Top 10 fruit/vegetable commodities imported to the United Kingdom for overall biomass

	Biomass		
Top 10 sources	Product	kg	%
1	bananas[a]	1,024,442,328	14.95
2	sweet oranges[c]	576,470,105	8.41
3	apples[c]	525,152,649	7.67
4	tomatoes[b]	398,293,964	5.81
5	onions[b]	280,975,650	4.10
6	grapes[c]	252,903,796	3.69
7	sweet peppers[b]	196,075,039	2.86
8	melons[d]	170,656,427	2.49
9	pineapples[a]	168,484,357	2.46
10	potatoes[e]	160,871,255	2.35

These are expressed in mass and the % that represents of the plant-based imports (supply). Shading represents the Food Foundation 5 categories: Hardy Heroes (not present in top 10); [a] Channel Hoppers; [b] Brexit Boosters; [c] EU Emigrants; [d] Globe Trotters. Commodities in grey are not listed in Food Foundation categories but are Globe Trotters. [e] Potatoes are classified nutritionally as a carbohydrate.

Research in context. This study adds important information to our understanding of the supply of key micronutrients to the United Kingdom and the relative importance of domestic versus imports and animal- versus plant-based supply. It allows an important comparison with a previous study[16] undertaken when exiting the European Union, EUCU and ESM about supply or demand. The dataset years available in our analysis include a number of important other global shocks, that is COVID-19, that have had further trade impacts. Developing new methods based on HMRC databases, our work allows specific countries and commodity supplies to be determined for key micronutrients, which allows two increasingly important axes/conditions to be considered—the proportion of domestic versus imports and the meat- versus plant-based supplies of key micronutrients.

The domestic supply of micronutrients has been relatively stable, but consumer demand has moved away from the fruit and vegetable products that can be easily grown in the United Kingdom[14]. The reliance of key EU countries to supply fruit and vegetables currently

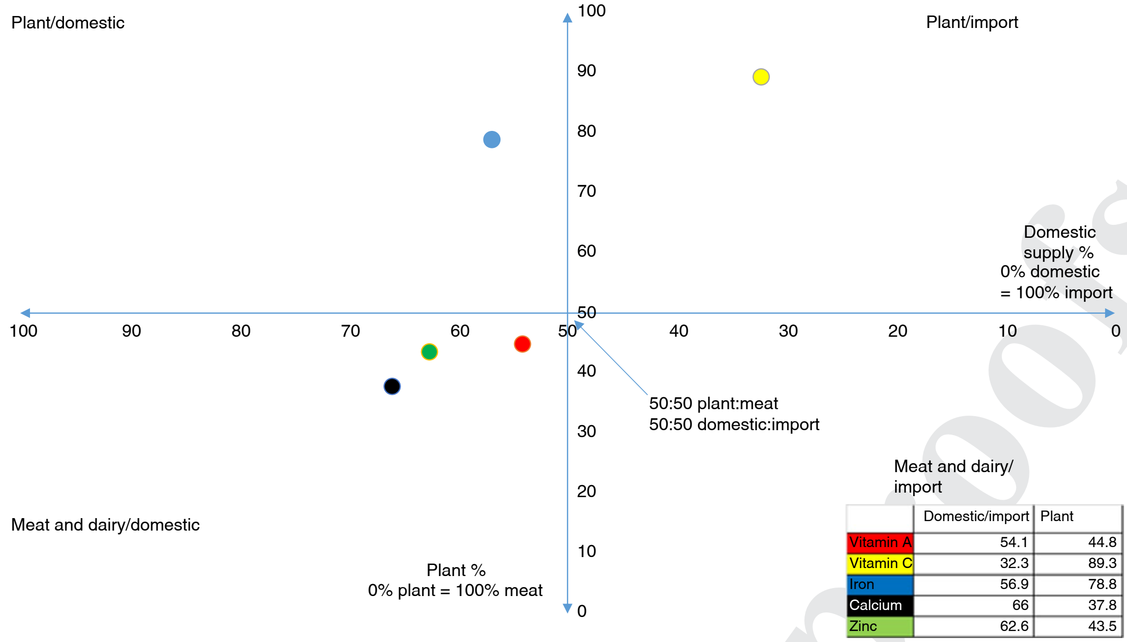

Fig. 4 | Current position for UK micronutrients in a scenario map. Micronutrient security in 2016r is plotted on a scenario map where domestic/import and animal/plant are the two uncertainty axes.

preferred by UK consumers brings into question a need to develop workable trading relationships with these EU partners and existing or new trade deals with other countries that can supply the micronutrients we require in the commodities we like to consume. Several products we like to consume come from Spain and other countries, which are vulnerable to climate impacts, for example, desertification[17,34]. Using a scenario analysis based on origin of supply and plant- or meat-based supply, we introduce four future scenarios and plot in which scenario our micronutrients currently sit in 2016r, and where the country was positioned at time points back to 1961. Taking a food systems approach[35] will require consideration of policies and behaviours to ensure the supply and/or demand is in place to ensure the security of the micronutrients in the future, which could play out quite differently as we learn lessons from COVID-19 both in terms of health and the environment. Analysing data back to 1961, we show in Fig. 2 and in Extended Data Fig. 2 how the baseline has moved within the scenarios, and the speed of change is likely to increase as we seek to address climate change and/or increasing public health issues.

Strengths and limitations. This study builds on earlier studies looking at micronutrient security using FAO databases and a shopping basket approach[16], but it uses the HMRC database to analyse micronutrient security, which allows the import countries to be unpacked and the specific plant-based, as opposed to meat-based, commodities to be determined.

The study is subject to a few limitations. The FAO data use quite broad food categories to define production statistics. This means that one has to use an index (an imagined basket of goods) to estimate what each food category contains in terms of actual produce. This basket is based on results from UK national food surveys. This basket can then yield a total mass of micronutrients that correspond to the FAO's reported mass of a food category. There are limitations with this approach, such as the possibility that the basket of goods will change over time, although over such a short time, such changes would be in the margins and not substantial.

Inaccuracies in the HMRC data exist, as described in our methods, and businesses wishing to commit fraud and evade VAT or other trading tariffs may underreport how much they import or misreport the nature of the goods they are importing. This could especially lead to underreporting of non-EU trade as these declarations are explicitly related to tariff collection. As a result, fraud may bias the data to make non-EU trade look small relative to EU trade. We have reported difficulties with trade reporting and the Rotterdam effect in our previous work on meat supply[36].

For some EU imports, net mass is not reported, as the Intrastat survey requires a report only in the 'supplementary unit' (for example, litres or carats). This is not an issue for us as all the products we analysed are solid goods and therefore reported in kg from the businesses.

Future directions. Our results have shown that supply and demand dynamics affect the United Kingdom's security of several key micronutrients. The use of a scenario analysis approach allows us to explore and visualize the future outcomes for the country based on two uncertainties, in our case the domestic/import and animal/plant-sourced supplies. The current baseline position for each micronutrient in the 2016r period was determined, just before the decision to exit the European Union and before implications of the COVID-19 pandemic were felt. Before COVID-19, discussions about self-sufficiency and trade–tariff wars were becoming very topical and widely debated as the United States and China started trade wars[36] and the discussions about the United Kingdom's position in the European Union was beginning to become more centre stage, as illustrated with fisheries[37].

The four scenarios introduced in the analysis (that is, self-sufficient plant source-rich diets; global trading plant source-rich diets; self-sufficient animal source-rich diets; global trading animal source-rich diets) could be explored in terms of how supply and/or demand would need to change from the current situation to meet that required in the future. For example, recommendations for a more plant-based diet as presented in EAT–*Lancet* or different dietary proportions of plant/animal axis (25%, 50%, 75% and 100% plant) and the flexitarian, pescatarian, vegetarian and vegan dietary choices[9,30,31] could all be considered with respect to micronutrient security and the range of policy, economic and behavioural levers needed to ensure security in such futures. In a similar way, one could consider a 25%, 50%, 100% shift towards self-sufficiency or imports in the trading uncertainty. These scenarios would provide insights into nutrient security, examine what uplift is needed and explore what needs importing or growing in the United Kingdom. Research[14,17] has shown the role of changing patterns in consumption over the past few decades, and our work shows how supplies currently meet these demands.

Our analysis and comparison with Macdiarmid's data from 2010r back to 1961 illustrates how change in trading patterns and meat/animal supply and demand have occurred over the past 60 years. This analysis back to 1961 (Extended Data Figs. 1 and 2) shows variation in the baseline, and desirable future scenarios will require considerable action and intervention to move from these baselines.

Our scenario approach could be used to consider how changing demand for plant- or animal-rich diets can be explored alongside whether the supply is sourced domestically or imported and thus how changing demands might be met through new supply either domestically or from other commodities.

The rising trend in reducing meat consumption, flexitarianism through to veganism, can be explored using our analysis to see at what point a population's overall security becomes close to a tipping point unless the supply dynamic changes accordingly. Our analysis of the ratios supplied from animals versus plants (Fig. 2) illustrate a move towards plants, albeit quite small changes at the macroscale, which mirrors quite small changes, so far, at the population-level diet. The rising trend of veganism amongst Generation Z[38,39] raises the question of at what point will the population's nutritional security be challenged without significant change in the food system providing the micronutrient supply.

Conclusion

There is an increased recognition that micronutrients need more attention when assessing a country's food security. The United Kingdom's supply of micronutrients involves a combination of domestic, imports and a range of plant-based and meat/dairy products. Comparing the United Kingdom's situation in 2016r with the previous assessment in 2010r and comparing with data stretching back 60 years (Fig. 2a–e and Extended Data Figs. 1 and 2) illustrates that there is variation in security and a reliance on certain imports and/or commodities. These are both likely to be affected in the future as we emerge from the COVID-19 pandemic and forge new trading relationships having left the European Union. There has been significant disruption in trading with the European Union since the United Kingdom officially left in January 2021[20], and it remains to be seen how permanent and significant these disruptions are while alternative trading supplies are developed. Looking at data from the 1970s (Extended Data Figs. 1 and 2) shows significant changes in trade (imports and exports) when the United Kingdom joined the European Union. We have been able to plot a 2 by 2 scenario framework based on two key uncertainties, which data stretching back to 1961 have highlighted as important variables, illustrating where the United Kingdom sat in 2016r and at a series of time points back to 1961 (Extended Data Fig. 2). This allows us to consider the challenges to supply and demand as consumers choose whether to adopt more plant-based diets and/or countries change their self-sufficiency and trading relationships. The National Food Strategy[13] recommends several changes to land use, diet and the food system that will influence how these scenarios evolve. A recent study estimating the costs of healthy and sustainable diets around the world has demonstrated that in high-income and upper-middle-income countries, dietary change interventions that incentivize adoption of healthy and sustainable diets can help consumers in those countries reduce costs while, at the same time, contribute to fulfilling national climate change commitments and reduce public health spending[11].

As dietary preferences continue to change and trading patterns face uncertainty in a post-COVID-19 world where discussions emerge regarding role of being self-sufficient, analyses such as ours could help explore where the pinch points might arise and which solutions in supply and/or demand will need to be introduced to ensure the dietary health of a country alongside planetary health. We identify an approach that will be invaluable for those wanting to transform the UK food system[13,35,40].

Methods

Trade and changes to several key micronutrients between 1962r and 2016r. *Micronutrient analysis—trade analysis.* We undertook a macroanalysis of FAO databases to understand the United Kingdom's domestic and imported supplies of food contributing to micronutrient security in 2015–2017 (2016r, rolling average). A rolling average is a calculation used to analyse data points by creating a series of averages of different subsets of the full dataset. Our rolling average is an average subset of the yearly data localized to three years around the stated year (for example: 1962r is a local average for the years 1961–1963). We use methods and results developed by Macdiarmid et al[16] to analyse micronutrient security and self-sufficiency. To investigate the micronutrient challenges for the EU exit time period, notably the year during which the EU exit referendum took place, we updated Macdiarmid et al.'s[16] 2010r figures. We also utilize a series of datasets dating back to 1961 presented in Macdiarmid et al[16].

Our analysis used production, export and import statistics from the FAO Food Balance Sheets (FBS)[32] database[15]. Macdiarmid et al[16] converted these same FBS figures into micronutrient masses for a time period ending at the rolling average for 2009–2011 (2010r). We looked to create micronutrient masses for a more up-to-date year. We sourced the FAO FBS figures in 2010r and compared with the figures for 2016r. The comparison between the two time periods enabled us to yield percentage changes in supply of different food categories and origins (domestic, exported, imported) between the two periods.

The FAO FBS statistics are converted into micronutrient supplies via an index, created by Macdiarmid for their figures[16], for our 2016r time period. This index is needed because the FAO FBS data[15] use broad food categories for their production statistics that cannot be easily associated with a micronutrient density (for example, 'wheat and products' is one such category). Macdiarmid et al.[16] create an index (an imagined basket of goods) to estimate what each food category contains in terms of actual produce; this is derived from data in the Living Costs and Food Survey[41]. This basket can convert the FAO FBS's reported mass of a food category into a total mass of different micronutrients.

We apply the percentage changes we calculated above to the basket-converted micronutrient masses calculated by Macdiarmid for the 2010r period. This effectively extrapolates 2010r figures to find the nutrient supply in 2016r. This, in effect, replicates the food basket process, converting the 2016r FBS supply figures into micronutrient supply.

The micronutrient supply figures are measured per capita per day to situate micronutrient supply within the context of health demands. In our extrapolation, we adjust for population changes to factor in any changes between 2010r and 2016r. To make this adjustment for population growth (using ONS data this is estimated at 6% between 2010r and 2016r)[42], we subtract the population growth percentage from all percentage change in FBS supply figures when extrapolating between the two time periods. Although this controls for population size change, we did not control for changes to the population pyramid, due to the short time period.

To compare the per capita per day supply with the UK population's health demands, we use the Reference Nutrient Intake (RNI) to calculate the recommended population-level intake for the UK population, which was weighted to the demographics at the time. RNI is the average daily dietary intake level that suffices to meet the nutrient requirements of nearly all (97.5%) healthy persons of a specific sex, age, life stage or physiological condition (such as pregnancy or breastfeeding)[43]. This approach allows us to take a macro-approach to the supply required for the population's health.

From this analysis, we can track the total mass per capita per day supply of micronutrients in 2016r that are (1) produced in the United Kingdom, (2) exported from the United Kingdom and (3) imported to the United Kingdom and distinguishing micronutrients that are (1) animal-based, (2) plant-based (within which we identify (3) from fruits and vegetables). The latter distinction is a new one we have made by distinguishing FBS food categories.

We can also understand this mass per capita per day in the context of percentage fulfilment of the average UK resident's RNI. This will provide the baseline for current supply, which will aid our exploration and visualization of future scenarios. To add further context, we have looked back at Macdiarmid's results stretching back to 1962r and a series of time points thereafter to 2010r and our extrapolated 2016r[16]. We have analysed the extended time period according to domestic/import/export in the Supplementary Information. However, in the Results and Figures section, we make our novel distinction between animal and plant (fruit and vegetable) for all these time points.

HMRC trade data for granularity on country and commodity. To gain a more detailed breakdown of UK imported plant-based micronutrient supply—both by country and by food source, we use trade data from HMRC UKTRADEINFO (Overseas Trade Statistics, or OTS)[44] supported by the Food Standards Agency (FSA) Trade Data Visualization Application[45], which allows data scraping of HMRC trade data. The FSA application is a query tool and allows downloads of a simplified and more flexible dataset than provided by HMRC UKTRADEINFO directly. HMRC data has the advantage of being more detailed than the FAO data used in the 2010r analysis by Macdiarmid et al[16]. HMRC's OTS lists imported food products, detailing each imported product's ten-digit commodity code, total mass and the specific country of origin. Our study utilizes the OTS's reported weight of fruits and vegetables imported into the United Kingdom from around the world and thus we can understand imported, plant-based (fruit and vegetable and other plant-based) sources of micronutrients. HMRC trade data are collected through different methods, depending on whether the trade is with non-EU or EU countries. UK businesses trading with non-EU countries are required to declare their imports to pay the legally obligated tariff. Trade between UK businesses and EU countries is collected from declarations in businesses' VAT returns and, for larger businesses, from a survey called the 'Intrastat survey'[46]. We decided to analyse 2017 only, unlike the three-year period used for the FAO FBS figures, because of the different nature of the data. HMRC OTS is released on a monthly basis and updated and refined for a few years afterwards. The FAO FBS is yearly and subject to fewer revisions. We are confident that any systematic errors in a particular OTS period (month) would be resolved by 12 months of data collection and Office for National Statistics quality assurance. We chose 2017 as it was the latest year used in the FAO FBS period we analysed.

These data requires knowledge of potential trade country-of-origin misattribution, commonly referred to as 'The Rotterdam Effect', which we have previously shown to influence meat trade analysis[36]. Imports can be misattributed (that is, to the wrong country of origin) because the last port of dispatch can be mistakenly entered as the country of origin. We observe this in how the EU OTS records bananas imported 'from' the Netherlands and oranges 'from' Ireland—both places where growing such products is infeasible. We have adjusted for this by filtering out of the EU OTS all commodity codes that can be determined as tropical and ungrowable in the EU nations (for example, bananas). However, while this eliminates some cases, there are fruits growable in the European Union that can still be misattributed to neighbouring countries, and so the Rotterdam Effect will still overstate certain neighbouring countries' contributions in those products.

Understanding micronutrient density of different food products. To transform the HMRC OTS data on imported produce into imported micronutrients, we need to understand the micronutrient density of imported produce. We use micronutrient data from Public Health England's McCance & Widdowson Composition of Foods Integrated Dataset (CoFID)[47], which holds estimations of the milligrams (mg) or micrograms (μg) of various micronutrients per 100 g of hundreds of foods, drinks and recipes. Where necessary and possible, a USDA database was used for missing values[48].

For some foods, nutritional content could not be found in the CoFID dataset for a specific micronutrient, although it was believed that the micronutrient was present; this is coded by CoFID as 'N' where 'a nutrient is present in significant quantities, but there is no reliable information on the amount'. In the very few cases where this occurs and we can't substitute with values from USDA, we have coded the micronutrient density as zero. This potentially underestimates the nutritional content of some foods that are imported. However, one should expect most foods with particularly high density to have a reliable figure recorded.

Synthesis of trade and micronutrient analysis. For this analysis, we combine the OTS and CoFID to estimate the total mass of micronutrients imported by the United Kingdom and understand the contributions of different countries of origin and commodity types.

To enable this synthesis, we matched the HMRC OTS ten-digit commodity codes to compositional data for foods that CoFID provides. CoFID does not categorize its compositional data according to commodity codes and it provides data for all manner of food from raw produce to fully prepared and cooked dishes. Although a significant portion of imported food will be prepared in some way before it is consumed, we match HMRC OTS commodity codes to CoFID's corresponding raw food ones unless suggested otherwise by the HMRC OTS commodity code description. Commodity code matching can be difficult for a few reasons. Some commodity codes lack a perfect analogue in CoFID because CoFID only has a broader category similar to the sub-types in the OTS (that is, CoFID has only density information for the broad category of 'easy peeler oranges', which must act as a proxy for the more specific commodity codes of 'clementines', 'tangerines' and so on) and vice versa. A commodity code can have no information available in CoFID where any proxy would be too inaccurate (for example, the dried bananas commodity code lacks a corresponding CoFID entry). The supplementary material shows which fruit and vegetable commodity codes were matched to which CoFID fruits and vegetables.

Once matching is complete, we multiplied the HMRC OTS kilograms of net mass for each commodity code by the corresponding CoFID nutritional density measures to establish the net mass of micronutrients imported from different countries of origin. See the below formula using vitamin A as an example:

$$\begin{aligned}&\text{OTS recorded kg of commodity imported from country}\\&\times\text{CoFID measure of density of vitamin A in commodity}\left(\frac{\text{mg}}{100\text{g}}\right)\\&\times 10 = \text{net mass of vitamin A via commodity imported from country}\ \ (\text{mg})\end{aligned}$$

The HMRC OTS' measure of weight can include packaging, which means that a record of 100 kg of tomatoes may include tin cans and therefore not actually mean 100 kg of solely tomatoes were imported. This means that our use of CoFID density figures converts weight attributable to inedible packaging into imported nutrients reflective of the food itself. This risks overestimating the nutritional value of imports. If the packaging problem is more or less uniform across products and countries of origin (that is, there are no particular countries/food types that on average report higher kg of packaging to HMRC), the packaging issue is not a problem when analysing the relative contributions of different products and countries of origin. Conversely, for example, if countries that are more distant can ship produce to the United Kingdom only in bulkier packaging to preserve freshness, then these countries may, in turn, have higher weight values assigned to exports, leading to an overestimation of nutritional contributions greater than that of closer countries.

One final complication is that much of what the United Kingdom imports as raw fruits and vegetables will go through preparations—chopping, peeling, cooking, frying, boiling and drying—before consumption. During this preparation, certain nutrients may be broken down or lost. This means that a proportion of certain nutrients that we calculate as part of the national supply may never actually be consumed by individuals.

One may consider using CoFID's micronutrient density for prepared food instead of raw food density to reflect the loss of food. However, this would also be inaccurate as many foods lose or gain mass from phenomena such as water loss/gain, impacting the density without actually impacting the total supply of nutrients. Using CoFID's prepared food density in those cases would actually distort the nutrients consumed. For example, to use the CoFID density for boiled beans on OTS mass of imported dried beans would understate the nutritional content of what is imported, prepared and ultimately consumed because the process of boiling increases the total mass of beans, in such cases, reducing its density without necessarily destroying any nutrients.

The two preparation effects of lost nutrients and transformed mass means that it is difficult to attribute nutrient density loss between raw food and food preparations in CoFID to single changes in either the mass of foods or to actual nutrient breakdown. For example, reduction in density for boiled beans and increases in density for dried tomatoes are probably the former, while reductions in folate and vitamin C in boiled broccoli are probably the latter. This means there is no easy fix. As stated earlier, we keep to CoFID's raw food density unless the OTS commodity code description suggests otherwise. This will mean we overestimate the nutrient supply versus what is actually consumed.

It is important to keep the food preparation problem into perspective. It is always the case that there will be differences between looking at macro-supply levels as opposed to the actual uptake and incorporation of the micronutrients in the human body. For example, there is much debate about bioavailability of some micronutrients in plants compared with animals[49], and the macroanalysis focuses on the supply in these two and not the bioavailability from these sources. Serra-Majem et al.[50] finds that FAO FBS (our method) estimates consumption of fruits, vegetables and roots 23%, 59% and 64% higher than Individual Dietary Surveys, respectively. It is important to highlight that focusing on supply always considers a 'best case' as it considers what is actually potentially available in terms of the *supply* of micronutrients rather than amounts actually in the human body, reflecting consumption patterns and bioavailability of nutrients post-consumption. It also still enables us to understand where the supply comes from. This means that our results are applicable in analysis of supply of nutritional security but less accurate with respect to the physiological nutritional security of individuals/populations.

OTS micro analysis enables us to identify the top ten fruit/vegetable commodities imported to the United Kingdom for each vitamin/mineral. We converted trade figures to what percentage of the UK's micronutrient RNI is supplied by specific fruits or vegetables in terms of the RNI. This conversion was done by referring back to the RNI percentage supplied by fruit and vegetable-based imports, according to FAO FBS. In addition, we made a comparison with the five Food Foundation Farming for 5-A-Day categories[14], which illustrates where commodities might be sourced, self-sufficiency possibilities and possible trading relationships required if we source less from the European Union. We shade code the top ten fruits and vegetables based on the categorization created by the Food Foundation[14], as it allows visualization of the ability for the United Kingdom to replace key products through trade and/or domestic production.

Scenarios—development and analysis. In this paper, we describe the United Kingdom's position in 2016r, before the COVID-19 pandemic and exit from the European Union, both of which have the potential to significantly change the micronutrient security of the United Kingdom. Our analysis presents the situation for a range of vitamins and minerals, chosen according to importance and/or level of insecurity observed in 2010r and expert opinion from nutritional epidemiology researchers on NDNS data and published data[51]. We focus on five of the seven micronutrients previously analysed[16] as these were most insecure and/or influenced by changes in plant-based diets or changing trade patterns. This gives us the 'business as usual' current situation, and comparing with 2010r, we can also look at where future trends would lead if the future were on the same trajectory as the previous decade. We used the approach described by Khalil and Alexander[23].

The United Kingdom's decision to leave the European Union and the COVID-19 pandemic have raised a number of important uncertainties, which can result in quite different scenarios/futures. A scenario can be seen as a set of plausible assumptions about the way the world works in future, and we undertook a scenario exercise developing a narrative of the four scenarios represented by the combinations of the extremes of the two critical uncertainties. We consider that commissions such as EAT–*Lancet*[9], UN food systems summit[52] and recent drivers/shocks such as COVID-19 and EU exit pose two key uncertainties that align with our supply and demand approach. The increasing calls for a change of diet might be considered a demand uncertainty, and the ability to domestically produce or import products could be considered as a supply uncertainty: (1) the amount of meat versus plant foods in diet and (2) the level of self-sufficiency versus global trading (potentially beyond European Union).

For these scenarios, we have sub-divided animal source data into red meat, white meat, milk/dairy and fish and focused our plant-import origin work on fruits and vegetables to allow us to undertake scenario work. We have sub-divided imports to the European Union and non-European Union (sub-divided where required). These four future worlds could be described as: (1) self-sufficient plant source-rich diets, (2) global trading plant source-rich diets, (3) self-sufficient animal source-rich diets and (4) global trading animal source-rich diets.

These four futures represent extremes, and our analysis has enabled us to determine where we sit for each micronutrient in 2016r. This approach would allow exploration of future diets, perhaps shifting to more plant-based or self-sufficiency. For example, we could explore the UK population shifting towards a more flexitarian, pescatarian, vegetarian and vegan diet by looking at movements along the plant/animal axis (25%, 50%, 75% and 100% plant). In a similar way, we could consider a 25%, 50%, 75% and 100% shift towards self-sufficiency or imports in the trading uncertainty, which we will explore for future publications. Our analysis of datasets back to 1961 highlights how changing trading relationships (joining the European Union in the 1970s) and dietary preferences have occurred in previous years and are thus uncertainties that cannot easily be predicted as certainly happening in one direction.

Data availability

Source data (HMRC, FAO, McCance and Widdowson) are publicly available and are alternatively available on request from the corresponding authors. Output data derived from MacDiarmid et al. and OTS can be found in Supplementary Data 1.

Code availability

Part of the data analysis was conducted using the R programming language. Further analysis was done in Excel (Supplementary Data 1). R files are available on request from the corresponding authors.

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References

1. Lasko-Skinner, R. & Sweetland, J. *Food in a Pandemic* (Demos, 2021).
2. Building better food systems for nutrition and health. *Nat. Food* (2021).
3. Gao, M. et al. Associations between body-mass index and COVID-19 severity in 6.9 million people in England: a prospective, community-based, cohort study. *Lancet Diabetes Endocrinol.* **9**, 350–359 (2021).
4. McAuliffe, S. et al. Dietary micronutrients in the wake of COVID-19: an appraisal of evidence with a focus on high-risk groups and preventative healthcare. *BMJ Nutr. Prev. Health* (2020).
5. James, P. et al. The role of nutrition in COVID-19 susceptibility and severity of disease: a systematic review. *J. Nutr.* **151**, 1854–1878 (2021).
6. Merino, J. et al. Diet quality and risk and severity of COVID-19: a prospective cohort study. Preprint at *medRxiv* https://www.medrxiv.org/content/10.1101/2021.06.24.21259283v1 (2021).
7. Ingram, J. Perspective: look beyond production. *Nature* **544**, S17 (2017).
8. Hauqe, S. E., Sakisaka, K. & Rahman, M. Examining the relationship between socioeconomic status and the double burden of maternal over- and child under-nutrition in Bangladesh. *Eur. J. Clin. Nutr.* **73**, 531–540 (2019).
9. Willett, W. et al. Food in the Anthropocene: the EAT–*Lancet* Commission on healthy diets from sustainable food systems. *Lancet* **393**, 447–492 (2019).
10. Hirvonen, K., Bai, Y., Headey, D. & Masters, W. A. Affordability of the EAT–*Lancet* reference diet: a global analysis. *Lancet Glob. Health* **8**, e59–e66 (2020).
11. Springmann, M. et al. The global and regional costs of healthy and sustainable dietary patterns: a modelling study. *Lancet Planet. Health* **5**, e797–e807 (2021).
12. Vaidyanathan, G. What humanity should eat to stay healthy and save the planet. *Nature* **600**, 22–25 (2021).
13. *The National Food Strategy: The Plan* (2021).
14. *Farming for 5-A-Day Food Foundation* (2017).
15. *Definition and Classification of Commodities* (Food and Agriculture Organization of the United Nations, 2017).
16. Macdiarmid, J. I., Clark, H., Whybrow, S., de Ruiter, H. & McNeill, G. Assessing national nutrition security: the UK reliance on imports to meet population energy and nutrient recommendations. *PLoS ONE* **13**, e0192649 (2018).
17. Scheelbeek, P. F. D. et al. United Kingdom's fruit and vegetable supply is increasingly dependent on imports from climate-vulnerable producing countries. *Nat. Food* **1**, 705–712 (2020).
18. Scheelbeek, P. F. D. et al. Health impacts and environmental footprints of diets that meet the Eatwell Guide recommendations: analyses of multiple UK studies. *BMJ Open* **10**, e037554 (2020).
19. *Build Back Better: Our Plan for Growth* (HM Treasury, 2021).
20. *UK Trade: May 2021* (Office for National Statistics, 2021).
21. Godfray, H. C. J. et al. Food security: the challenge of feeding 9 billion people. *Science* **327**, 812–818 (2010).
22. Tilman, D. & Clark, M. Global diets link environmental sustainability and human health. *Nature* **515**, 518–522 (2014).
23. Khalil, S. & Alexander, S. *Shaping the Future of Global Food Systems: A Scenarios Analysis* (World Economic Forum and Deloitte, 2017).
24. Elliott, M. & Bhunnoo, R. Scenarios for transforming the UK food system to meet global agreements. *Nat. Food* **2**, 310–312 (2021).
25. Baer-Nawrocka, A. & Sadowski, A. Food security and food self-sufficiency around the world: a typology of countries. *PLoS ONE* **14**, e0213448 (2019).
26. Clapp, J. Food self-sufficiency: making sense of it, and when it makes sense. *Food Pol.* **66**, 88–96 (2017).
27. Schneider-Petsinger, M. *National Self-Sufficiency or Globalization is Not a Binary Choice* (Chatham House, 2020).
28. Geyik, O., Hadjikakou, M. & Bryan, B. Spatiotemporal trends in adequacy of dietary nutrient production and food sources. *Glob. Food Sec.* **24**, 100355 (2020).
29. *Factsheet Number 24: Flour Fortification* (Federation of Bakers, 2017); https://www.fob.uk.com/wp-content/uploads/2017/01/FS25-Flour-Fortification.pdf
30. Springmann, M. et al. Health and nutritional aspects of sustainable diet strategies and their association with environmental impacts: a global modelling analysis with country-level detail. *Lancet Planet. Health* **2**, e451–e461 (2018).
31. Springmann, M., Godfray, H. C. J., Rayner, M. & Scarborough, P. Analysis and valuation of the health and climate change cobenefits of dietary change. *Proc. Natl Acad. Sci. USA* **113**, 4146–4151 (2016).
32. *Food Balance Sheets: A Handbook* (Food and Agriculture Organization of the United Nations, 2001); http://www.fao.org/docrep/003/X9892E/X9892E00.HTM
33. Wood, S., Smith, M. R., Fanzo, J., Remans, R. & DeFries, R. S. Trade and the equitability of global food nutrient distribution. *Nat. Sustain.* **1**, 34–37 (2018).
34. *Climate Change Vulnerability Index* (Verisk Maplecroft, 2016); http://reliefweb.int/sites/reliefweb.int/files/resources/verisk%20index.pdf
35. Bhunnoo, R. & Poppy, G. A national approach for transformation of the UK food system. *Nat. Food* **1**, 6–8 (2020).
36. Poppy, G., Baverstock, J. & Baverstock-Poppy, J. J. Meeting the demand for meat—analysing meat flows to and from the UK pre and post Brexit. *Trends Food Sci. Technol.* **86**, 569–578 (2019).
37. Li-Jing, L. et al. Environmental and economic impacts of trade barriers: the example of China–US trade friction. *Resour. Energy Econ.* **59**, 101144 (2020).
38. Appleby, T. From membership to partnership: the EU and its relations with the UK after Brexit: the Fisheries dimension. *Eur. Foreign Aff. Rev.* **25**, 551–572 (2020).
39. Kymäläinen, T., Seisto, A. & Malila, R. Generation Z food waste, diet and consumption habits: a Finnish social design study with future consumers. *Sustainability* **13**, 2124 (2021).
40. Poppy, G. & Baverstock, J. Rethinking the food system for human health in the Anthropocene. *Curr. Biol.* **29**, R972–R977 (2019).
41. *Living Costs and Food Survey* (Office for National Statistics, 2017); https://www.ons.gov.uk/peoplepopulationandcommunity/personalandhouseholdfinances/incomeandwealth/methodologies/livingcostsandfoodsurvey
42. *Population Estimates for UK, England and Wales, Scotland and Northern Ireland* (Office for National Statistics, 2017).
43. *Dietary Ref Values for Food Energy and Nutrients in the UK* (HMSO, 1991).
44. *The HMRC's Trade Statistics Database: UKTRADEINFO* (HMRC, accessed); https://www.uktradeinfo.com/
45. *UK Trade Data Visualisation* (Food Standards Agency, 2019); https://foodstandards.shinyapps.io/TradeDataVis/

46. *Intrastat Survey* (European Trade Center, 2018); http://www.intrastat.ro/di_en.php
47. McCance, R. A. & Widdowson, E. M. *McCance and Widdowson's The Composition of Foods* 7th edn (Royal Society of Chemistry and Public Health England, 2015).
48. *FoodData Central* (US Department of Agriculture, 2019); https://fdc.nal.usda.gov/
49. Melse-Boonstra, A. Bioavailability of micronutrients from nutrient-dense whole foods: zooming in on dairy, vegetables, and fruits. *Front. Nutr.* **7**, 101 (2020).
50. Serra-Majem, L. et al. Comparative analysis of nutrition data from national, household, and individual levels: results from a WHO-CINDI collaborative project in Canada, Finland, Poland, and Spain. *J. Epidemiology Community Health* **57**, 74–80 (2003).
51. Whitton, C. et al. National diet and nutrition survey: UK food consumption and nutrient intakes from the first year of the rolling programme and comparisons with previous surveys. *Br. J. Nutr.* **106**, 1899–1914 (2011).
52. *Food Systems Summit* (UN, 2021); https://www.un.org/en/food-systems-summit

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Author contributions

G.M.P., J.B. and J.J.B.-P. jointly designed the study and interpreted the results. J.J.B.-P. conducted the analysis. G.M.P. and J.B. wrote the manuscript with inputs from J.J.B.-P. G.M.P., J.B. and J.J.B.-P. reviewed and edited the manuscript.

Competing interests

The authors declare no competing interests.

Additional information

Extended data Extended data is available for this paper at https://doi.org/10.1038/s43016-022-00538-3.

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s43016-022-00538-3.

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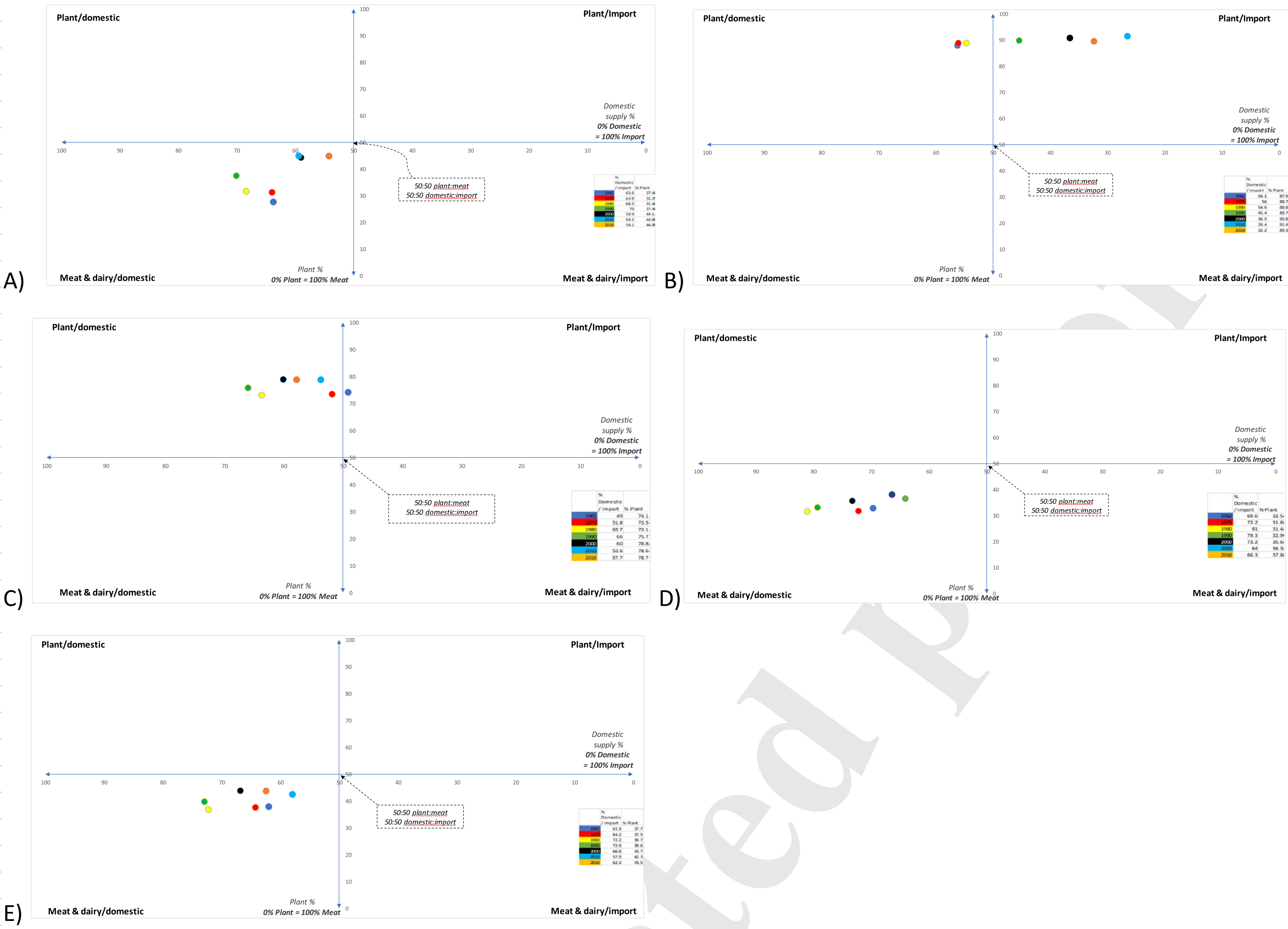
Extended Data Fig. 1 | Change in micronutrient security between time periods during 1961–2017. % Changes in key micronutrient security for a range of time periods illustrating changes before joining the EU, immediately after joining the EU and other comparisons from the period 1961–2017.



Extended Data Fig. 2 | Micronutrient security scenario plots from 1961–2017. Micronutrient security from 1961–2017 is plotted on a scenario map where domestic/import and animal/plant are the two uncertainty axes. The following micronutrients are plotted a) vitamin A; b) vitamin C; c) Iron; d) Calcium and e) Zinc.

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