# **UK’s fruit and vegetable supply increasingly dependent on imports from climate vulnerable producing countries.**

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**Abstract**

Domestic contribution to total fruit and vegetable supply in the UK decreased from 42% in 1987 to 22% in 2013. The impact of this changing pattern of UK fruit and vegetable imports, from countries with different vulnerabilities to projected climate change, on the resilience of the UK food system is currently unknown. Here, we used the UN FAO bilateral trade database over a period of 27 years to estimate changes in fruit and vegetable supply in the UK, and the NDGAIN climate vulnerability categories to assess the climate vulnerability of countries supplying fruit and vegetables to the UK. The diversity of fruit and vegetable supply has increased from 21 crops, comprising the top 80% of all fruit and vegetables supplied to the UK in 1987, to 34 crops in 2013. The contribution of tropical fruits has rapidly increased while that of more traditional vegetables, such as cabbages and carrots, has declined. The proportion of fruit and vegetables supplied to the UK market from climate vulnerable countries increased from 20% in 1987 to 32% in 2013. Sensitivity analyses - using climatic and freshwater availability indicators - supported these findings.

Increased reliance on fruit and vegetable imports from climate vulnerable countries could negatively affect the availability, price and consumption of fruit and vegetables in the UK, affecting dietary intake and health particularly of older people and low-income households. Inter-sectoral actions across agriculture, health, environment, and trade are critical in both the UK and countries that export to the UK to increase the resilience of the food system, and support population health.

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Introduction

Fruit and vegetablesare key components of healthy diets, but globally their consumption is well below current international dietary recommendations. Just 30% of adults and 18% of children eat the recommended five portions of fruit and/or vegetables per day in England (1), with similar or lower levels reported for Scotland, Northern Ireland and Wales (2-4). Low fruit and vegetable consumption, together with low consumption of whole grains, low intake of nuts and seeds, and excessive salt intake, make up the top five dietary risk factors for morbidity and premature mortality in the UK (5) and in combination are a leading risk factor for diabetes, cardiovascular disease and several types of cancer (6-8). In the UK, fruit and vegetable consumption is directly associated with income and has a parabolic association with age; adults under 25 and over 65 years of age consuming the lowest quantities ((1-4, 9)). Fruit and vegetables typically have lower environmental footprints than animal sourced foods, and their increased consumption may therefore be important in improving food system sustainability. The dual contribution of fruit and vegetables to both health and sustainability is increasingly recognised in national dietary guidelines and other reports (10-13).

A rise in international trade and imports has increased the availability and diversity of fruit and vegetables in the UK in recent decades (14). The cost of ensuring year-round access to out-of-season crops and their increased processing requirements, such as washing, cutting, cold-chain, have kept fruit and vegetable prices high (15). There is also growing evidence that increasing climate and other environmental changes are affecting agricultural production (16-22). Food cropping systems (23) are particularly vulnerable to adverse effects in hot climates (21, 24, 25), and in locations with lower institutional and/or farmer-initiated adaptive capacity (23, 26). These climate-mediated impacts on food supply are evident in both the country of food production, and in those countries dependent on food imports (27). The impacts of droughts in California, floods in Latin America, and extremely cold winters in Italy and Spain on fruit and vegetable supplies in the UK (28) (29) illustrate the vulnerability of national food systems to distant climate events(30). Temporary food shortages can significantly raise food prices and may negatively affect food consumption, especially among low-income groups(31). There are several potential leverage-points in the food system to increase resilience and ensure the future supply of fruit and vegetables, including shifts in trade strategy to reduce dependency on countries and food cropping systems vulnerable to climate change and support for the consumption of domestically-grown fruit and vegetables.

To understand resilience of food systems and to inform policy options around future food production and trade strategies requires detailed analysis of agricultural product flows. Using openly available data for the UK on the international flow of primary and processed agricultural products (combining FAOSTAT (32) data and published algorithms (33)), we describe an approach to quantify climate-associated risks to national fruit and vegetable supply. The study aims to define a method to understand the resilience of food systems, defined as the robustness of supply in the face of projected climate change, with a focus on fruit and vegetables. This method will enable the identification of challenges and leverage points to improve the resilience and sustainability of the UK food system in the future, map implications for other countries dependent on imports, and explore the role that the UK can play in global food system resilience – particularly for fruit and vegetable supply.

Results

**Fruit and vegetable supply 1987-2013**

Food supply in the UK increased from 3227 kcal per capita per day in 1987 to 3414 kcal per capita per day in 2013, an increase of 5.8% . Supply of all fruit and vegetables in the UK (fresh and processed) increased from 417g in 1987, to 495g in 2000 and 563g in 2013, a 35% increase. Over this period, per capita fruit supply increased slightly more than that of vegetables (150g, 187g and 225g for fruit and 268g, 308g and 338g for vegetables, in 1987, 2000 and 2013, respectively), resulting in an increase in the overall contribution of fruit to total fruit and vegetable supply (Figure 1A). It is important to note that national food supply figures do not equate to food consumption, or individual dietary intake. Despite accounting for loss and waste pre-farm gate and along the supply chain, these food supply figures overestimate per capita fruit and vegetable supply as they do not account for waste at household level (34)).

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***Figure 1: Change in supply of fruit and vegetables in the UK 1987-2013.*** *1A. Fruit and vegetable crops supply (g and %) in the UK in 1987, 2000 and 2013. 1B Movement of share of crops in the "top-18" (the top 18 most supplied crops to the UK, by weight) between 1987, 2000 and 2013. 1C. Percentage of crop families making up total fruit and vegetable supply in the UK in 1987, 2000 and 2013.*

The diversity of UK fruit and vegetable supply increased over the study period. In 1987, 21 crops comprised the top 80% of total fruit and vegetables supplied to the UK, and this rose to 27 in 2000 and 34 in 2013. Additions to the list of fruits were mostly tropical fruit varieties such as pineapples (increasing from 0.9% to 1.4% of overall fruit and vegetable supply) and lemons & limes (increasing from 0.6% to 0.9%). The share of bananas increased substantially from 3.0% of total fruit and vegetable supply in 1987 to 7.8% in 2013. There was a decline in the share of more traditional vegetables in total supply, for example, cabbages declined from 7.5% in 1987 to 2.5% in 2013, peas from 5.0% to 1.3% and carrots from 7.0% to 5.8% (Figure 1B and Supplementary Figure 2). When grouped into crop aggregates, between 1987 and 2013 there were declines in the share of leafy vegetables (15% to 8.0%) and legumes (5.6% to 1.6%), and increases in berries (11% to 18%) and Bromeliaceae (0.9% to 1.4%). (Figure 1C).



Figure 2: **Countries producing at least 1% of UK fruit and vegetable supply in 1987 and 2013** , identifying share of supply and Notre Dame Global Adaptation Initiative (NDGAIN) country score category. The NDGAIN categories are quintiles of the NDGAIN scores (1-100) based on indicators of vulnerability to climate change as well as readiness to adapt to climate disruptions (35). All countries producing fruit and vegetables for UK supply are assigned a climate vulnerability category, ranging from 1 (most vulnerable) to 5 (least vulnerable/resilient).

**Dependency on climate vulnerable countries**

Domestic contribution to total fruit and vegetable supply in the UK, including fresh fruit and vegetables as well as processed foods containing fruit and vegetables, decreased substantially from 42% in 1987 to 31% in 2000 and 22% in 2013. When considering fresh produce only, as reported by DEFRA (36), these numbers are 55% in 1988, 43% in 2000 and 33% in 2013 [*Supplementary Table 1*]. There was a simultaneous increase in the number of countries from which fresh and processed fruit and vegetables were imported: from 12 major producing countries (those accounting for at least 1% of total fruit and vegetable supply to the UK) in 1987 to 21 countries in 2013 (Figure 2).

Total fruit and vegetable provision in the UK has become more dependent on climate vulnerable production areas. In 2013, approximately 32% of all fruit and vegetable supply for the UK market were produced in countries that were classified as having high or intermediate vulnerability to climate change (NDGAIN category 1-4, whereby **1 =** extreme vulnerability; **2 =** high vulnerability; **3 =** intermediate-high vulnerability; **4 =** intermediate vulnerability). This proportion has increased from 20% in 1987. Large differences in climate vulnerability of country of production were evident between crop aggregates. For example, in 2013, 99% of leafy vegetables and 95% of root vegetables were produced in climate resilient countries, while 66% of all berries (including bananas), 54% of all citrus fruits and virtually all pineapples and papayas (100% and 99.7% respectively) originated from climate-vulnerable countries (Figure 3). The legume group (e.g. peas and beans) showed the largest increase in proportional supply from climate vulnerable production areas rising from 0.2% to 19% of supply between 1987 and 2013.



Figure 3: **NDGAIN vulnerability index of country of origin of major fruit and vegetable families consumed in the UK**. Figure is showing the proportion supply of various crop groups by climate vulnerability of supplying country (1987; 2000 and 2013): **1 =** extreme vulnerability; **2 =** high vulnerability; **3 =** intermediate-high vulnerability; **4 =** intermediate vulnerability; **5 =** low vulnerability.

Fruit and vegetable supply from countries with a current peak daytime temperature of >25°C (average over the growing season) increased substantially from 25.0% to 48.0% over the period 1987 to 2013, and supply from countries with average peak temperatures >30°C dropped marginally (from 4.2% to 1.6%) over the same time period. Fruit and vegetable supply from countries with <200mm of precipitation in the growing season increased from 22% to 26% over the period 1987 to 2013 (see Supplementary Tables 2 and 3 for details and country specific rainfall data); 13% of the supply in 2013 came from countries with the most growing season precipitation (>400mm). The supply of fruit and vegetables from countries likely to face “high” to “extremely high” water scarcity has increased from 40.6% to 53.7% over the period 1987 to 2013. At the same time, there has also been a notable increase in fruit and vegetable supply from countries classified as facing low to medium-low water stress (from 1.5% in 1987 to 10.6% in 2013) (Figure 4a-c).



Figure : **Proportion of fruit and vegetables supplied by production stratified by year for three environmental parameters;** A) average peak temperatures (°C) in the growing season; B) precipitation over the growing season; C) projected water stress by 2040 (WRI-index)

**Consumption of fruit and vegetables by income, age and country (England, Wales, Northern Ireland and Scotland)**

Analyses of National Diet and Nutrition Survey (NDNS) consumption data did not show major differences between country of the UK or sex strata in the percentage consumption of crops of which >50% are produced in climate vulnerable countries (i.e. berries, citrus, pineapples and papayas) compared to ‘resilient crops’ (e.g. apples and pears [see Supplementary Tables 4 and 5 for country and sex specific results]). When stratified by age group, there was a positive association between age and consumption of crops predominantly supplied by climate vulnerable countries, increasing from 23% of total fruit and vegetable consumption in the youngest age group to 32% in the oldest age group (Figure 5). Average daily fruit and vegetables consumption in the youngest age group (16-24 years of age) was significantly lower (3.0 portions) than in the three other age groups (3.7 portions). Fruit and vegetable consumption patterns also varied by income group, both in quantity and type of fruit and vegetables consumed. Whilst consumption of the top-8 fruits and vegetables were identical in low-, middle- and high-income households, compared with members of low-income households, members of high-income households consumed more citrus and berries (26% vs. 23%) (Supplementary Table 6). Fruit and vegetable diversity was slightly higher in high-income households with 25 crops making up the top 80% fruit and vegetable consumption, as compared to 20 and 21 for middle and low-incomes households respectively.



Figure 5: **Proportion of consumption of berries and citrus fruits by age group.** Consumption of the two most “vulnerable” crop aggregates (berries and citrus fruits) in total fruit and vegetable consumption - by age group (based on NDNS wave 7&8).

**Discussion**

The approach used here to map national food supply, both domestically produced and imported, enables the assessment of an important aspect of resilience in national food systems - dependence on foods produced in climate vulnerable countries. Our analysis identified that over the period from 1987 to 2013, fruit and vegetable supply to the UK diversified substantially and the domestic supply of fruit and vegetables as a proportion of total supply fell. Importantly, we have shown that in 2013 nearly one third of the total fruit and vegetables supply to the UK market (and the majority of novel fruit and vegetable varieties) were imported from climate vulnerable countries. Analysis of fruit and vegetable consumption patterns in the UK identified that fruit produced in climate vulnerable countries were more likely to be consumed in high-income households and by people >50 years of age.

Transition towards year-round availability of fruit and vegetable crops from tropical countries (37), and in particular changes in supply of fresh vegetables from African countries (38), and trade flows for some vegetables (39) have previously been reported. We used improved bilateral trade data (33) to disaggregate import data and determine countries of origin of production, enabling detailed and comprehensive analysis of fruit and vegetable trade for the UK.

Projected climate change will have differing impacts on the global agriculture sector (40). Climate change is projected to substantially alter current international food trade flows (41) via reductions in agricultural yields in tropical countries and increases (or smaller reductions) in yields in temperate countries (42). Furthermore, significant harvest failures in fruit and vegetable sectors in the next 10-15 years are not implausible, especially for crops predominantly grown in climate vulnerable production areas (21, 22, 43). While specific evidence on fruit and vegetables is limited, the 2008 food price crisis showed that food shocks in staple crop yields, that were partially weather-related, can lead to protectionist responses such as export bans from key exporters (44).

Other changes in global, regional or national economic and/or political systems may further redirect patterns of trade to and from the UK. For example, the rapid increase in the import of tropical varieties has partly been facilitated by relatively low fossil fuel prices (45). If these prices were to increase in the future, for example, due to reduced supply, regulations and/or influence of competing energy sources, long-distance trade of fruit and vegetables could become less viable. Furthermore, the withdrawal of the UK from the European Union at the end of 2020 could lead to major changes in UK fruit and vegetable trade and, especially in case of a no-deal scenario, could increase dependency on climate vulnerable countries even further (46).

This study is subject to a number of limitations. Alongside 10-20 ‘popular’ crops, many fruit and vegetable crops are consumed infrequently and/or in small quantities; therefore, analyses were limited to those in the top 80% of fruit and vegetables consumed in the UK, assuming that results could be extrapolated to all fruit and vegetable supply. The large global datasets used in this study have caveats. Trade data from FAO are dependent on data quality, which varies greatly between reporting countries (47). The database (32) adjusted with the Kastner *et al* algorithm (33) provides improved and unique data on country of origin, but the model is also subject to several assumptions for which applicability may vary globally. Sub-national differences in crop origin could not be established, hence the same crops might be subject to different levels of climate-related risks within a country [ok? some suggested rewording]. The different indices used to determine climate vulnerability of production countries are modelled estimates and are subject to a number of assumptions. Even when extensively calibrated, their applicability is likely to vary by geographic location. The use of NDGAIN scores for climate change vulnerability is subject to similar limitations and assumptions; as scores are assigned at national level, within-country heterogeneity is not considered. Fruit and vegetables are often cultivated in more favourable circumstances or higher quality land, and so the score may not fully represent on-the-ground conditions in production regions, and this could have led to misclassification of climate change vulnerability scores at sub-national level.

Our results indicate that a growing proportion of UK fruit and vegetable supply is produced in countries vulnerable to climate change. Many of these are already-water stressed, and climate change poses additional challenges. Whilst advances in agricultural production are expected to increase resilience of these production countries, the high dependency on international trade partners could be a risk or a risk diversification strategy for possible supply disruptions. The larger the geographical spread of trade partners, the likelihood that local or regional supply disruptions will have a large impact on UK imports is reduced. However, the increasing dependency on climate vulnerable production areas increases the risk of supply disruptions to the UK. As average fruit and vegetable consumption in the UK is already relatively low in most population groups, the potential of reduced fruit and vegetable availability and increased prices would likely hamper the attainment of recommended guideline intake levels. Furthermore, climate change may increase perishability of some fresh produce and increase food loss and waste.

Though beyond the scope of this analysis, the impact of UK demand for fruit and vegetables on the global environment is an important consideration. For example, approximately 76% of the fresh water consumed in the supply of fruit and vegetables to the UK is drawn elsewhere, including from countries with a high risk of water scarcity such as Spain, Egypt, South Africa, Chile, Morocco, Israel and Peru (48). Large variability in the environmental footprints of different cropping systems identifying opportunities for system-wide learning to improve food system sustainability (49).

Related to the above, there is an urgent need to explore strategies to address the increased vulnerability of UK fruit and vegetable supply. A first major strategy could involve extended collaboration and investments in mitigation of, and adaptation to, climate change in agriculture – specifically in climate-vulnerable countries. Such actions are especially relevant if production is more resource efficient elsewhere and would reduce overall resource use and emissions of the UK food system. There are currently no legal restrictions on trade with producers in climate vulnerable areas or in areas with unequal access to resources. Those countries that produce for export are more likely to have the financial resources to ensure stable production, and by sharing natural resources with smaller and subsistence farming systems, they may consequently experience even larger production challenges in these years. Collaborations between environmental and food system actors could enable mapping out a clear overview of resource access and use, for varying sizes of agricultural systems, related to food production at sub-national level and thereby highlight potential economic and natural capital trade-offs in the production and trade of crops (50).

Shifting to lower reliance on imports would be another possible strategy, and could be approached from both production and consumption perspectives. From the production side, the potential for horticultural expansion in the UK could be explored, including novel urban agricultural systems, such as vertical and soil-less agriculture, whilst focussing on both the potential for increased production and lower environmental impacts. Although scenarios vary, climate change impacts could potentially improve the growing circumstances for fruit and vegetables in temperate climate such as in the UK (51). Furthermore, although typically low at the production side, greenhouse gas emissions of fruit and vegetable supply could substantially increase because of increasing distance and changing mode of transport of shipment from the producing country to UK markets. An import strategy that seeks to minimise adverse effects on producer countries and reduce the environmental footprint of imports together with increased local supply would, therefore, also contribute to climate change mitigation and wider aspects of sustainability. As with all transformational change, economic, environmental, health and other benefits and trade-offs of expanding horticultural production should be carefully mapped to assess feasibility and public and political acceptability. Any transformational strategies would require extensive collaboration throughout the food system to identify tractable solutions.

# Methods

**Identification of most commonly supplied fruit and vegetables in UK**

We used the openly-accessible FAOSTAT data for the period 1986-2013 (the range of years for which Food Balance Sheet data and food trade algorithms are available) as the source of information on the supply of fruit and vegetables available for consumption in the UK (32, 33). We selected 1987, 2000 and 2013 (13-year intervals) for data presentation in this study. *Full data is available in the LSHTM Data Compass repository (See data availability statement)*. To assess how closely these food supply data reflected the fruit and vegetables that are consumed in the UK (rather than traded, wasted, used in industrial processes), FAOSTAT food supply data from 2013 were compared to food consumption data from an overlapping three-year average (2012-2014) of the UK National Diet and Nutrition Survey (NDNS (9)). From both data sources, we included food items defined as non-starchy fruits and vegetables (52). In the case of dried or processed foods that contain a proportion of fruit and vegetables, we assigned a value in grams of ‘primary crop equivalent’ as defined by the FAO (32). Food items such as soft drinks, confectionery, cakes and ice cream that may contain fruit and vegetables but are not included in “5-a-day” recommendations were excluded (Supplementary Figure 2).

The individual level consumption data of UK adults (16+ years) were pooled to calculate weighted average per person daily consumption of each fruit and vegetable crop:

(1)

*Where: C = average consumption in the population per fruit/vegetable crop; γ = specific fruit or vegetable; i= specific individual in the survey; n=total number of individuals in the survey; ϑ = specific food item containing fruit/vegetable; m=total number of food items containing fruit/vegetable; E = primary crop equivalent conversion factor; w = adjusted survey weight; p= total survey population*

We then assessed whether FAOSTAT fruit and vegetable *supply* *data* were proportionately similar to NDNS fruit and vegetable *consumption data* and showed that both data sources identified a similar list of crops that represented 80% of fruit and vegetable supply (in kg per capita per year). For the purposes of this study we therefore used FAOSTAT data as a proxy of fruit and vegetable consumption in the UK. Detailed results of these initial analyses can be found in Supplementary Figure 3 & Supplementary Notes).

**Trends over time in UK fruit and vegetable supply**

For each study year, we identified the fruit and vegetables that together comprised 80% of total fruit and vegetable supply for consumption in the UK (in kg per capita per year) and grouped them into 13 crop aggregates (Supplementary Table 7). Crops that are not taxonomically fruit or vegetables, but are commonly consumed as such, including mushrooms and legumes, were included in the analyses. Aggregation was based on likely within-group substitutions or crops with similar dietary function and aggregate groups were a combination of taxonomic families (e.g. Solanaceae) and crop groups (e.g. ‘berries’). The remaining 20% of the supply distribution, comprising a large number of fruits and vegetables supplied in small quantities, were excluded from the current analysis (Supplementary Figure 2). We adjusted supply figures for apples (55% of domestic supply and 86% of foreign imports used for non-alcoholic consumption (53)) and grapes (45% of supply for non-alcoholic consumption (54)) in order to remove the estimated share of supply used for cider and wine production respectively. We did not include the FAOSTAT composite categories “other vegetables” (17.9%) and “other fruit” (2.2%) as quantities were relatively small and difficult to trace back to country of origin.

**Identifying country of production of UK fruit and vegetable supply**

Country of production of fruit and vegetable crops supplied to the UK was determined using the accounting method developed by Kastner and colleagues (33) with specific calculations performed for crops included in this study. In brief, the FAOSTAT databases on bilateral trade flows and production (32) were used to estimate the trade of a fruit or vegetable from the country of production to the country of final consumption (in this case the UK) effectively excluding intermediate countries in which food processing, storage or shipping dispatch commonly distort trade data. The method relies on a set of factors to convert processed products into primary equivalents and assumes that domestic supply (‘consumption’) of a given crop is the result of domestic production plus imports minus exports (55). The proportion of domestic production contributing to national consumption of each given crop is known, but that proportion remains unknown for its exports. As some crops will be imported, processed and exported without in-country consumption, the assumption is made that the shares of imports and domestic production are proportional for both ‘consumption’ and exports, and therefore consistent production and supply values can be established for crops on a worldwide scale (using standard FAO data, by crop category).

The calculations resulted in a database of fruits and vegetables (primary crop by tonnes) estimated to have been supplied to the UK (including domestic production) on an annual basis. From the database, we selected each fruit and vegetable crop that was listed in our established ‘top 80%’ and extracted data on the proportion of total supply by production country. Data for these analyses are available from 1987 to 2013 and here we report the results for 1987, 2000 and 2013: results for intermediate years can be obtained from the corresponding author. Sensitivity analysis, using a three-year rolling average (1987-1989; 1999-2001; 2011-2013), showed very marginal differences with single year results (Supplementary Figure 4).

**Mapping climate vulnerability of the countries of origin of UK fruit and vegetable supply**

Countries producing fruit and vegetables for UK supply were assigned a climate vulnerability category, ranging from 1 (most vulnerable) to 5 (least vulnerable/resilient), based on the NDGAIN country index scores that includes indicators of vulnerability to climate change as well as readiness to adapt to climate disruptions (35). Although not specifically focussed on agriculture, we used the score as a proxy for national agricultural adaptation capacity. Scores are given at a country-level and are not able to account for within-country heterogeneity in eco-climatic zones. We used the latest NDGAIN scores (2015) and projected them on the trade patterns of all years between 1987 and 2013 (i.e. to estimate what proportion of fruit and vegetables would be produced in climate vulnerable countries if we currently had a similar import pattern as in each of the analysed years). In this way we were able to assess the direction of change (from the 1980s until the 2010s) in trade patterns, and hence explore dependency of the UK on fruit and vegetable supply from countries with different climate vulnerability scores (35).

Using the reference period 2016-2018, additional analyses of climate vulnerability were carried out using proxy measures of direct heat and drought-related stress on fruit and vegetable production (data from the National Oceanic and Atmospheric Administration (NOAA) database (56)). For these analyses, two indicators were developed for each country that supplied fruit and vegetables to the UK: 1) average day-time temperature [categorised as: <25°C; 25-30°C; 30+°C] and 2) average precipitation [categorised as <200mm; 200-400mm; 400+mm] in the main growing season of tomatoes (the most frequently consumed crop and selected as a proxy for other fruit and vegetables). A projected water stress indicator for 2040 (the ratio of water withdrawals to supply - under a business-as-usual RCP8.5/SSP2 scenario as defined by the World Resource Institute (57)) – was used to assess trends in fruit and vegetable supply from countries likely to face future water scarcity.

**Estimating impacts in the UK from supply to consumption**

Using the latest available data on dietary intake in the UK (NDNS waves 7 and 8; years 2014-2016), we performed cross-sectional stratified analysis on fruit and vegetable consumption in low-, middle- and high-income households (categorised in tertiles), among different age groups (16-25; 26-50; 51-64; and 65+) and by country of the UK (England, Wales, Scotland and Northern Ireland). We focused on differences in consumption of “climate vulnerable crop groups” defined as >50% of total supply originating from climate vulnerable countries.

Data were analysed using R Studio [version 1.2.5033], STATA/IC [version 16.1] and Microsoft Excel 2019.

Authors’ individual contributions

* PS, RG, AT, AH & AD contributed to the conceptualisation of the study
* PS, CM, TK & CA contributed to the data curation
* PS, CM & CA conducted the formal analysis
* AD & PS contributed to the funding acquisition
* PS conducted the investigation
* PS, CM, TK, RG, AH & AD designed the methodology
* PS developed the visualisation of results
* PS wrote original draft
* CM, TK, CA, RG, SJ, AT, AH & AD Commented on/edited the draft

# Competing interests

This study was funded by The Wellcome Trust [Grant: 205200/Z/16/Z & 210794/Z/18/Z]. The authors have no competing interests to declare.

Data availability

Datagenerated in this study will be made available upon reasonable request through LSHTM Data Compass (<https://datacompass.lshtm.ac.uk/> - [Scheelbeek, P](http://datacompass.lshtm.ac.uk/view/creators/0fe8b708819e948f096f56b4204e924e.html) (2020). *Extended Data - UK’s fruit and vegetable supply increasingly dependent on imports from climate vulnerable producing countries.* [Dataset]. London School of Hygiene & Tropical Medicine, London, United Kingdom. [58]

Source data for figures and tables:

Figure 1:

* Food and Agriculture Organization of the United Nations. FAOSTAT database. Food and Agriculture Organization of the United Nations, Rome, Italy 2013.

Figure 2 & 3

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Figure 5:

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* Bates B, Lennox A, Prentice A, Bates C, Page P, Nicholson S, et al. on behalf of the Food Standards Agency in Wales, Welsh Government and Public Health England: National Diet and Nutrition Survey Rolling Programme (NDNS RP) Results from Years 2-5 (combined) for Wales (2009/10-2012/13)

Code availability

Code and algorithms generated in this study will be made available upon reasonable request from the corresponding author.

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# Figure Legends

**Figure 1: Change in supply of fruit and vegetables in the UK 1987-2013.** 1A. Fruit and vegetable crops supply (g and %) in the UK in 1987, 2000 and 2013. 1B Movement of share of crops in the "top-18" (the top 18 most supplied crops to the UK, by weight) between 1987, 2000 and 2013. 1C. Percentage of crop families making up total fruit and vegetable supply in the UK in 1987, 2000 and 2013.

**Figure 2: Countries producing at least 1% of UK fruit and vegetable supply in 1987 and 2013 , identifying share of supply and Notre Dame Global Adaptation Initiative (NDGAIN) country score category.** The NDGAIN categories are quintiles of the NDGAIN scores (1-100) based on indicators of vulnerability to climate change as well as readiness to adapt to climate disruptions (35). All countries producing fruit and vegetables for UK supply are assigned a climate vulnerability category, ranging from 1 (most vulnerable) to 5 (least vulnerable/resilient).

**Figure 3: NDGAIN vulnerability index of country of origin of major fruit and vegetable families consumed in the UK.** Figure is showing the proportion supply of various crop groups by climate vulnerability of supplying country (1987; 2000 and 2013): 1 = extreme vulnerability; 2 = high vulnerability; 3 = intermediate-high vulnerability; 4 = intermediate vulnerability; 5 = low vulnerability.

**Figure 4: Proportion of fruit and vegetables supplied by production stratified by year for three environmental parameters;** A) average peak temperatures (°C) in the growing season; B) precipitation over the growing season; C) projected water stress by 2040 (WRI-index)

**Figure 5: Proportion of consumption of berries and citrus fruits by age group**. Consumption of the two most “vulnerable” crop aggregates (berries and citrus fruits) in total fruit and vegetable consumption - by age group (based on NDNS wave 7&8).

# Inventory of Supplementary Information

* ***Supplementary Table 1: Fresh produce supply and trade statistics (Source DEFRA).***
* ***Supplementary Table 2.******Weighted Percentage of Fruit and Vegetable Supply from Top Countries and Average Rainfall.*** Average rainfall was determined for each country from data provided by the National Centers for Environmental Information – National Oceanic and Atmospheric Administration (NOAA – Climate Online Data) and stratified based on average rainfall. Percent total fruit and vegetable supply for countries included in each rainfall category (<200, 200-400, >400) is presented in Figure X4 for years 1987, 2000, and 2013.
* ***Supplementary Table 3. Percent Total Fruit and Vegetable Supply from Countries Based on Average Rainfall Category***
* ***Supplementary Table 4. Percent consumption of crops by sex for crops of which >50% are produced in climate vulnerable countries vs “resilient crops” in 2013.*** NDNS consumption data stratified by sex (supplementary table 4) and country (supplementary table 5) did not show major differences in terms of consumption of crops of which >50% are produced in climate vulnerable countries as compared to more “resilient crops” (those where <50% are produced in climate vulnerable countries).
* ***Supplementary Table 5. Percent consumption of crops by country for crops of which >50% are produced in climate vulnerable countries vs “resilient crops” in 2013***
* ***Supplementary Table 6. Percent consumption of crops by income group in 2013.***Consumption patterns across income groups varied slightly in terms of amount consumed, and variety of fruits and vegetables consumed. High income households consumed slightly more citrus and berries (26%) compared to low income households (23%).
* **Supplementary Table 7:** **Non-starchy fruit and vegetable crop aggregates supplied for the UK market**. Main fruit and vegetable crop aggregates by crop family and examples of the main crops in each aggregate.
* ***Supplementary Figure 1. Proportion of fruit and vegetable supply produced in the UK since 2013.*** *Proportion of fruit and vegetable supply produced in the UK since 2013 (last year considered in this study)*
* ***Supplementary Figure 2. Percent share of all fruit and vegetable supply for years 1987, 2000, and 2013****.*A large number of fruits and vegetables were supplied infrequently and/or in small quantities and were therefore excluded from the analysis. For each year (1987-2013), the top 18 crops were selected for inclusion in the analysis. Figure X2 shows all crop supply percentages for years 1987, 2000, and 2003. For intermediate years, please contact the author.
* ***Supplementary Figure 3. 2013 Fruit and Vegetable Consumption vs Supply Data for the top 20 crops.*** We compared the FAOSTAT fruit and vegetable *supply data* and the NDNS fruit and vegetable *consumption data* to determine whether the FAOSTAT data could be used as a proxy of fruit and vegetable consumption in the UK. As 2013 was the only year the two datasets overlapped, we have only compared data for that year. Figure X1 shows the top 20 crops for the supply data and corresponding supply and consumption percentages which indicates that supply data is comparable to consumption data for 2013. The NDNS consumption data included Strawberries, Peaches/Nectarines, Green beans, and Blueberries in their top 20 crops, which were not in the top 20 for the supply data. However, these four fruits and vegetables only accounted for 5% of total consumption in the UK.
* ***Supplementary Figure 4: Sensitivity analysis comparing a 3-year rolling average to single year measurement.*** *A. The % of total supply for each individual crop; B. Differences between fruit and vegetable supply top 10 comparing single year estimates with 3-year rolling averages.*

# ***Supplementary Note 1 - Cleaning NDNS consumption data to derive grams of primary crop equivalent produced***

Supplementary Information and Extended Data

# **UK’s fruit and vegetable supply increasingly dependent on imports from climate vulnerable producing countries.**

**Pauline FD Scheelbeek**

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**Carmelia Alae-Carew**

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# Supplementary Tables

***Supplementary Table 1: Fresh produce supply and trade statistics (Source DEFRA).*** *Available at:* [*https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment\_data/file/822083/hort-dataset-01aug19.xlsx*](https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/822083/hort-dataset-01aug19.xlsx)\*1987 was not available from DEFRA statistics

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Year | Metric | Unit | Fruit | Vegetables | Fruit + Vegetables |
| 1988\* | UK production | *1000 tonnes* | 435.6 | 2856 | 3292 |
| Imports | *1000 tonnes* | 2086 | 719.5 | 4556 |
| (Re)exports | *1000 tonnes* | 49 | 39.1 | 88.1 |
| ***Supply produced in UK*** | **%** | **17.6** | **80.8** | **54.8** |
| 2013 | UK production | *1000 tonnes* | 522.5 | 2370 | 2893 |
| Imports | *1000 tonnes* | 3836 | 2225 | 6061 |
| (Re)exports | *1000 tonnes* | 143 | 80.5 | 223.5 |
| **Supply produced in UK *(%)*** | **%** | **12.4** | **52.5** | **33.1** |

***Supplementary Table 2.******Weighted Percentage of Fruit and Vegetable Supply from Top Countries and Average Rainfall.*** Average rainfall was determined for each country from data provided by the National Centers for Environmental Information – National Oceanic and Atmospheric Administration (NOAA – Climate Online Data) and stratified based on average rainfall. Percent total fruit and vegetable supply for countries included in each rainfall category (<200, 200-400, >400) is presented in Figure X4 for years 1987, 2000, and 2013.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Countries | 2013 | 2000 | 1987 | Average Rainfall in growing season (mm) |
| Colombia | 2.10 | 0 | 0 | 1374 |
| Brazil | 2.72 | 2.56 | 1.52 | 1131 |
| Costa Rica | 2.92 | 2.37 | 0 | 650 |
| Ecuador | 1.44 | 0 | 0 | 556 |
| Dominican Republic | 1.61 | 0 | 0 | 483 |
| United States | 2.57 | 5.31 | 2.71 | 438 |
| United Kingdom | 24.6 | 37.7 | 48.0 | 335 |
| China | 4.84 | 2.75 | 0 | 330 |
| India | 1.95 | 0 | 0 | 330 |
| Netherlands | 5.62 | 4.36 | 4.06 | 329 |
| Belgium | 1.93 | 1.67 | 1.15 | 329 |
| South Africa | 3.40 | 3.63 | 3.04 | 312 |
| Poland | 1.76 | 0 | 0 | 301 |
| France | 3.76 | 5.38 | 5.86 | 295 |
| Morocco | 1.20 | 0 | 0 | 257 |
| Egypt | 1.39 | 0 | 0 | 257 |
| Italy | 10.0 | 11.1 | 11.7 | 248 |
| Spain | 17.5 | 14.3 | 10.4 | **184** |
| Turkey | 3.00 | 3.84 | 1.79 | **157** |
| Portugal | 2.71 | 2.32 | 0 | **136** |
| Greece | 1.30 | 2.67 | 5.48 | **130** |
| Chile | 1.64 | 0 | 0 | **118** |
| Cyprus | 0 | 0 | 1.28 | **30.1** |
| Israel | 0 | 0 | 2.96 | **5.49** |

***Supplementary Table 3. Percent Total Fruit and Vegetable Supply from Countries Based on Average Rainfall Category***

|  |  |  |  |
| --- | --- | --- | --- |
| Average Rainfall | 2013 | 2000 | 1987 |
| <200 | 26.2 | 23.2 | 21.9 |
| 200-400 | 60.5 | 66.6 | 73.8 |
| >400 | 13.4 | 10.2 | 4.24 |
| Grand Total | 100 | 100 | 100 |

***Supplementary Table 4. Percent consumption of crops by sex for crops of which >50% are produced in climate vulnerable countries vs “resilient crops” in 2013.*** NDNS consumption data stratified by sex (supplementary table 4) and country (supplementary table 5) did not show major differences in terms of consumption of crops of which >50% are produced in climate vulnerable countries as compared to more “resilient crops” (those where <50% are produced in climate vulnerable countries).

|  |  |  |
| --- | --- | --- |
| Crop | Female % | Male % |
| Tomatoes | 20.8 | 25.8 |
| Bananas | 10.2 | 9.67 |
| Oranges | 8.62 | 10.6 |
| Apples | 8.53 | 8.68 |
| Onions, dry | 6.05 | 6.53 |
| Carrots and turnips | 5.88 | 4.52 |
| Grapes | 5.278 | 4.34 |
| Cauliflower and broccoli | 4.23 | 3.17 |
| Peas, green | 3.53 | 3.73 |
| Tangerines, mandarins, clementine, satsumas | 2.77 | 2.04 |
| Lettuce and chicory | 2.68 | 2.39 |
| Cabbages and other brassicas | 2.61 | 2.33 |
| Cucumbers and gherkins | 2.37 | 1.95 |
| Chillies and peppers, green | 2.19 | 1.92 |
| Pears | 2.17 | 2.37 |
| Strawberries | 2.02 | 1.24 |
| Mushrooms and truffles | 1.97 | 2.24 |
| Peaches and nectarines | 1.39 | 1.33 |
| Sweet corn | 1.38 | - |
| String beans | 1.18 | 1.23 |
| Pumpkins, squash and gourds | 1.17 | - |
| Plums and sloes | 1.05 | 1.21 |
| Avocados | 1.01 | - |
| Mangoes, mangosteens, guavas | 0.95 | - |
| Blueberries | - | 1.52 |
| Raspberries | - | 1.20 |
|  |  |  |
| Climate Vulnerable Crops | **29.0** | **29.4** |
| Resilient Crops | **71.0** | **70.6** |

***Supplementary Table 5. Percent consumption of crops by country for crops of which >50% are produced in climate vulnerable countries vs “resilient crops” in 2013***

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| Crop | England % | Wales % | Scotland % | Northern Ireland % |
| Tomatoes | 22.9 | 27.5 | 26.0 | 23.9 |
| Bananas | 9.91 | 8.95 | 11.0 | 12.7 |
| Oranges | 9.61 | 9.23 | 10.3 | 10.9 |
| Apples | 8.50 | 8.21 | 10.5 | 9.13 |
| Onions, dry | 6.34 | 5.01 | 7.00 | 6.00 |
| Carrots and turnips | 5.09 | 5.88 | 6.16 | 6.43 |
| Grapes | 5.01 | 4.60 | 3.34 | 3.68 |
| Cauliflower and broccoli | 3.68 | 3.75 | 3.80 | 5.26 |
| Peas, green | 3.54 | 4.87 | 4.03 | 3.82 |
| Lettuce and chicory | 2.69 | 1.89 | 1.67 | 1.71 |
| Cabbages and other brassicas | 2.57 | 2.89 | 1.09 | 2.67 |
| Tangerines, mandarins, clementines etc | 2.38 | 2.26 | 2.83 | 2.92 |
| Cucumbers and gherkins | 2.32 | 1.76 | 1.18 |  |
| Pears | 2.26 | 2.21 | 2.38 | 2.94 |
| Chillies and peppers, green | 2.09 | 1.49 | 2.20 | 2.15 |
| Mushrooms and truffles | 2.08 | 2.40 | 2.40 | 2.02 |
| Strawberries | 1.71 | 1.58 | 1.04 | 1.39 |
| Peaches and nectarines | 1.39 | - | 1.72 | - |
| String beans | 1.26 | 1.46 | - | - |
| Blueberries | 1.25 | - | - | - |
| Plums and sloes | 1.18 | - | - | - |
| Sweet corn | 1.14 | 1.17 | - | 2.49 |
| Raspberries | 1.06 | - | - | - |
| Grapefruit and pomelos | - | 1.74 | - | - |
| Pineapples | - | 1.16 | 1.30 | - |
|  |  |  |  |  |
| Climate Vulnerable Crops | **29.3** | **27.9** | **28.7** | **30.0** |
| Resilient Crops | **70.7** | **72.1** | **71.3** | **70.0** |

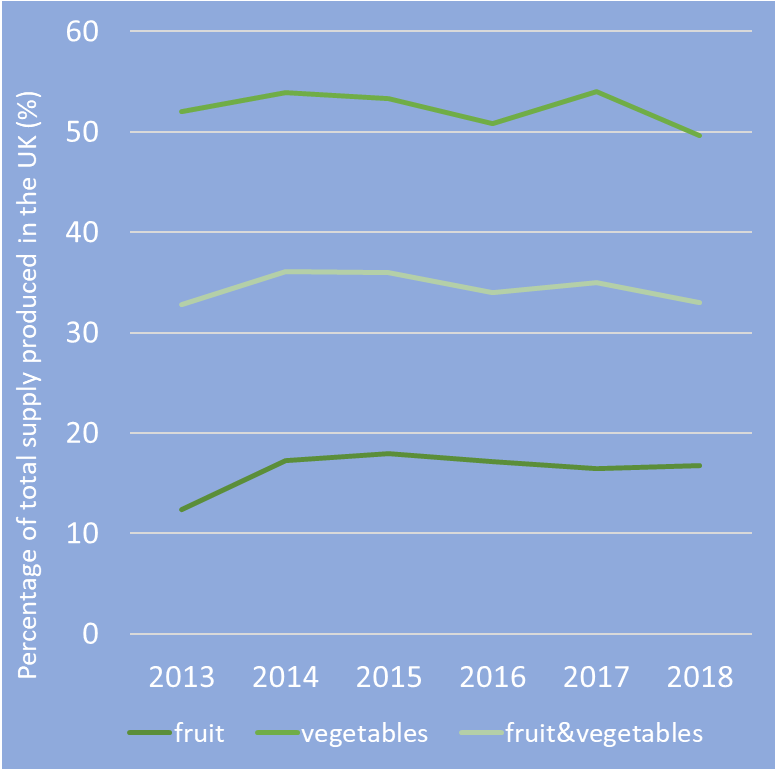
***Supplementary Table 6. Percent consumption of crops by income group in 2013.***Consumption patterns across income groups varied slightly in terms of amount consumed, and variety of fruits and vegetables consumed. High income households consumed slightly more citrus and berries (26%) compared to low income households (23%).

|  |  |  |  |
| --- | --- | --- | --- |
| Crop | High Income % | Middle Income % | Low Income % |
| Tomatoes | 21.2 | 26.6 | 23.4 |
| Bananas | 9.17 | 11.4 | 9.48 |
| Apples | 8.60 | 8.53 | 8.53 |
| Oranges | 8.28 | 10.2 | 10.3 |
| Onions, dry | 6.20 | 6.04 | 7.20 |
| Grapes | 4.88 | 5.41 | 4.92 |
| Carrots and turnips | 4.83 | 5.38 | 5.51 |
| Peas, green | 3.59 | 3.17 | 4.06 |
| Tangerines, mandarins, clementines, satsumas | 3.36 | 1.90 | 1.67 |
| Cauliflower and broccoli | 3.29 | 3.38 | 3.73 |
| Lettuce and chicory | 2.97 | 2.25 | 2.26 |
| Cabbages and other brassicas | 2.87 | 2.36 | 2.42 |
| Chillies and peppers, green | 2.45 | 1.54 | 1.80 |
| Mushrooms and truffles | 2.42 | 1.80 | 1.89 |
| Cucumbers and gherkins | 2.07 | 2.21 | 2.45 |
| Pears | 1.85 | 2.26 | 2.82 |
| Raspberries | 1.84 | - | - |
| Blueberries | 1.53 | 1.53 | - |
| Strawberries | 1.44 | 1.45 | 1.83 |
| Pumpkins, squash and gourds | 1.29 | - | - |
| Sweet corn | 1.25 | - | 1.00 |
| String beans | 1.23 | 1.57 | - |
| Peaches and nectarines | 1.19 | - | 1.75 |
| Grapefruit and pomelos | 1.12 | - | - |
| Avocados | 1.07 | - | - |
| Sweet Potatoes | - | 1.52 | - |
| Mangoes, mangosteens, guavas | - | - | 1.58 |
| Plums and sloes | - | - | 1.36 |
|  |  |  |  |
| Citrus and berries | **25.6** | **26.4** | **23.3** |
| Apples and Pears | **10.5** | **10.4** | **11.3** |

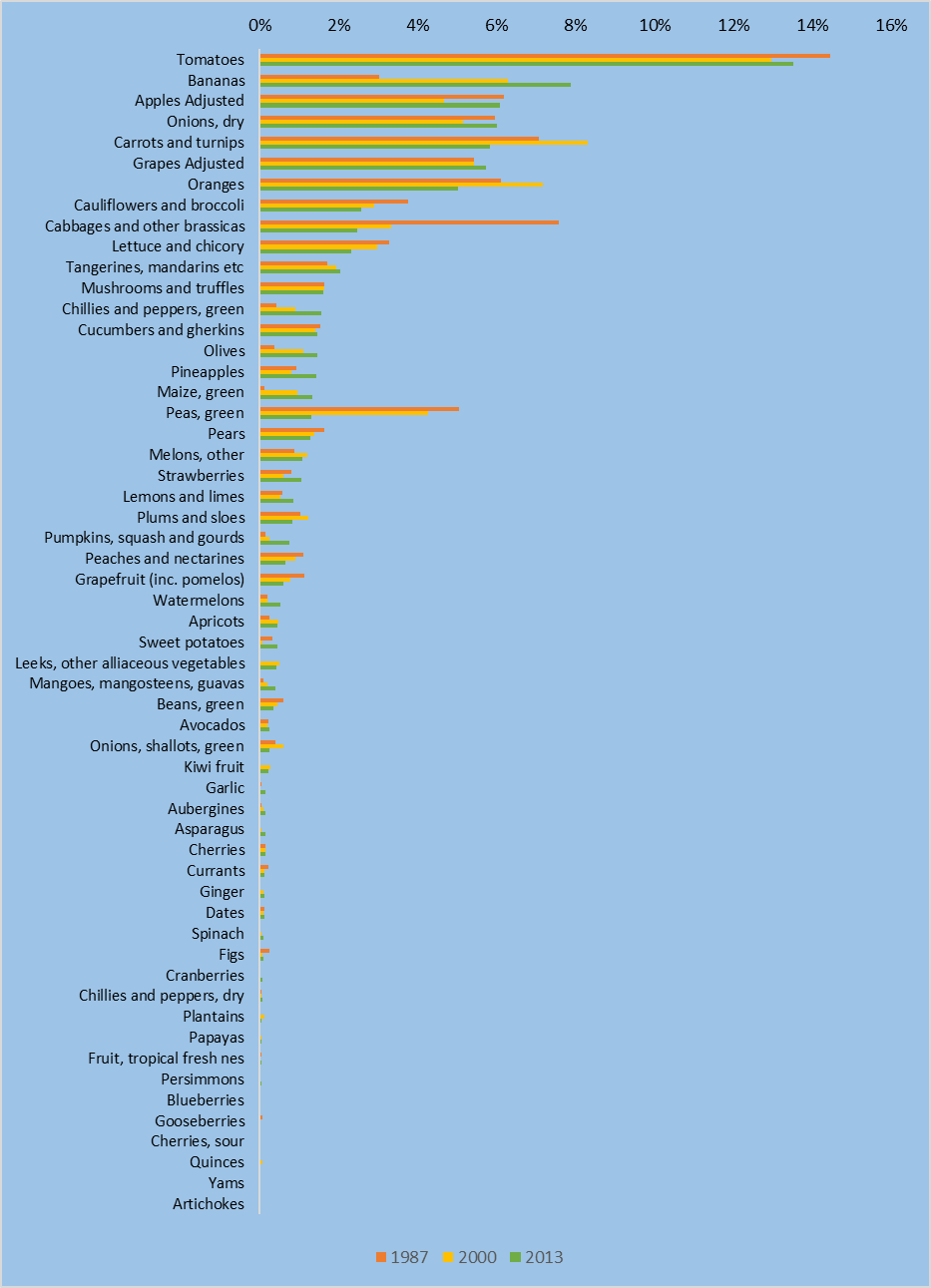
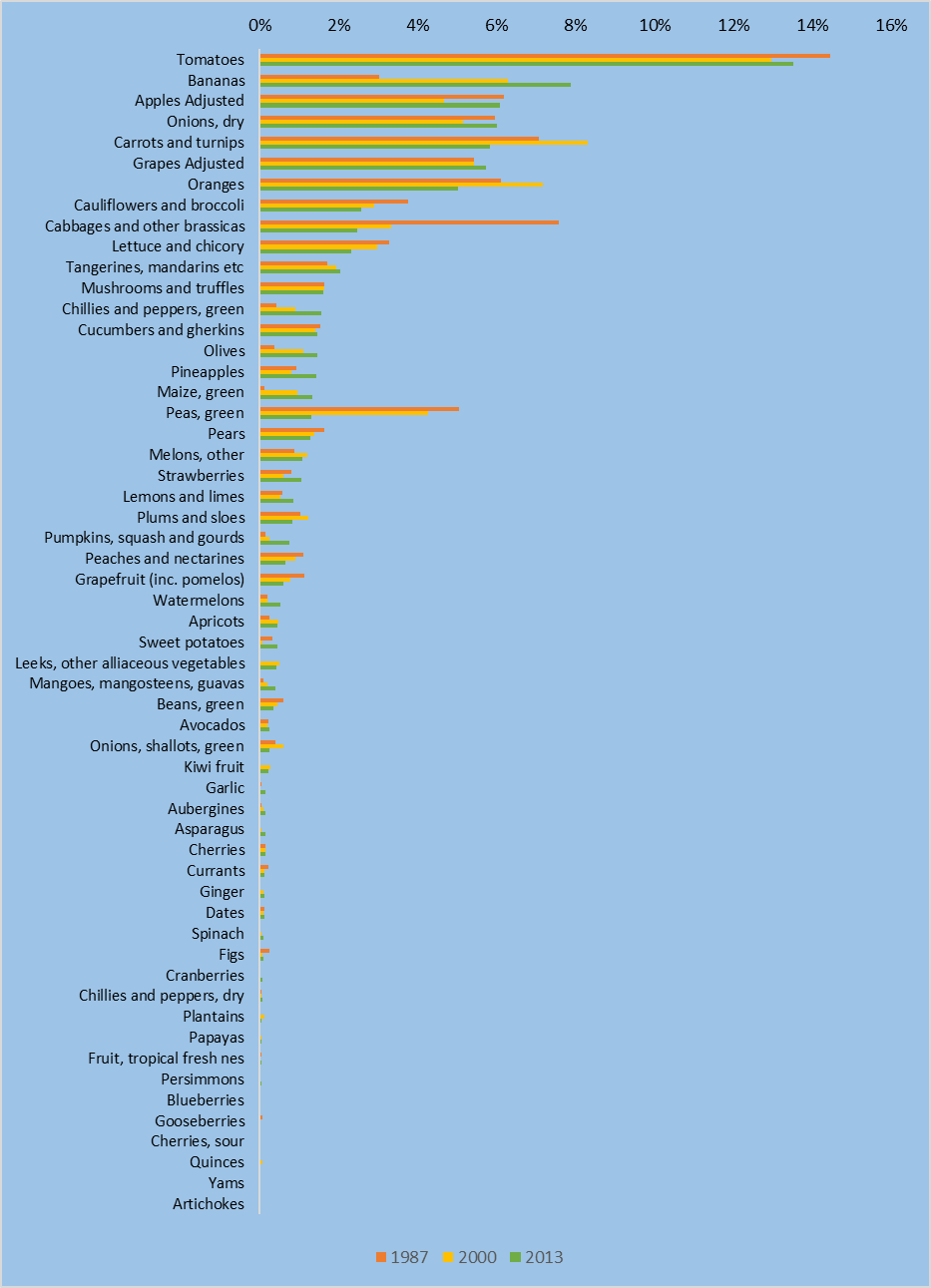
**Supplementary Table 7:** **Non-starchy fruit and vegetable crop aggregates supplied for the UK market**. Main fruit and vegetable crop aggregates by crop family and examples of the main crops in each aggregate.

|  |  |
| --- | --- |
| **Crop family** | **Main crops from each family (UK supply)** |
| **Solanaceae** | tomatoes, chillies, peppers |
| **Berries** | bananas, grapes, raspberries, strawberries, blueberries, melons |
| **Citrus fruits** | oranges, tangerines |
| **Leafy vegetables & brassicas** | cabbages, lettuce, spinach, cauliflower |
| **Pommes** | apples, pears |
| **Root vegetables** | carrots, onions, beetroot |
| **Cucurbitaceae** | cucumbers, pumpkins, squash, melons |
| **Legumes** | peas, beans |
| **Fungi** | mushrooms, truffles |
| **Drupes** | peaches, plums |
| **Poaceae** | sweet corn |
| **Bromeliaceae** | Pineapples |
| **Caracacea** | Papayas |

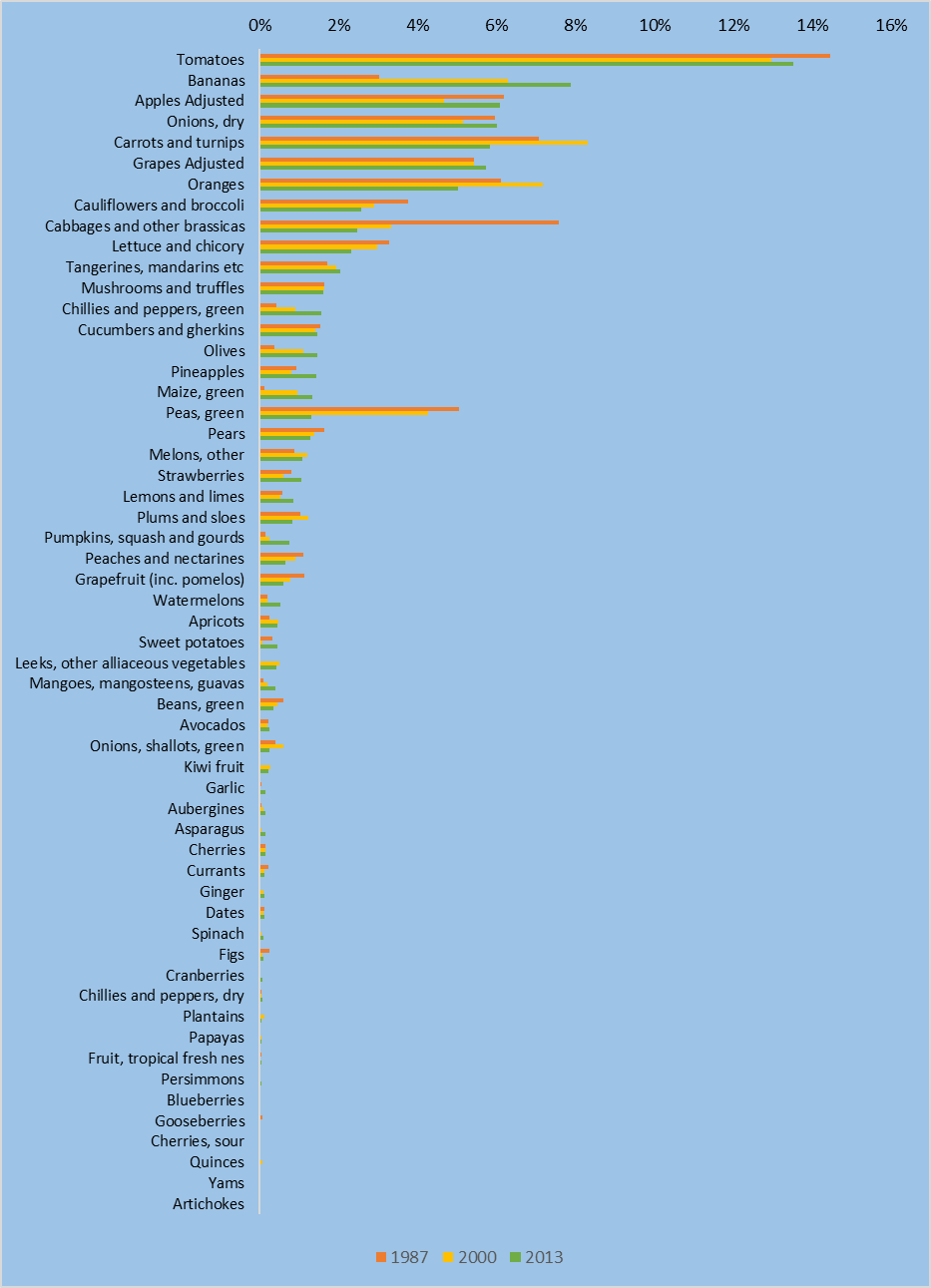
# Supplementary Figures



***Supplementary Figure 1. Proportion of fruit and vegetable supply produced in the UK since 2013.*** *Proportion of fruit and vegetable supply produced in the UK since 2013 (last year considered in this study)*



2013 Top 18 Fruits and Vegetables

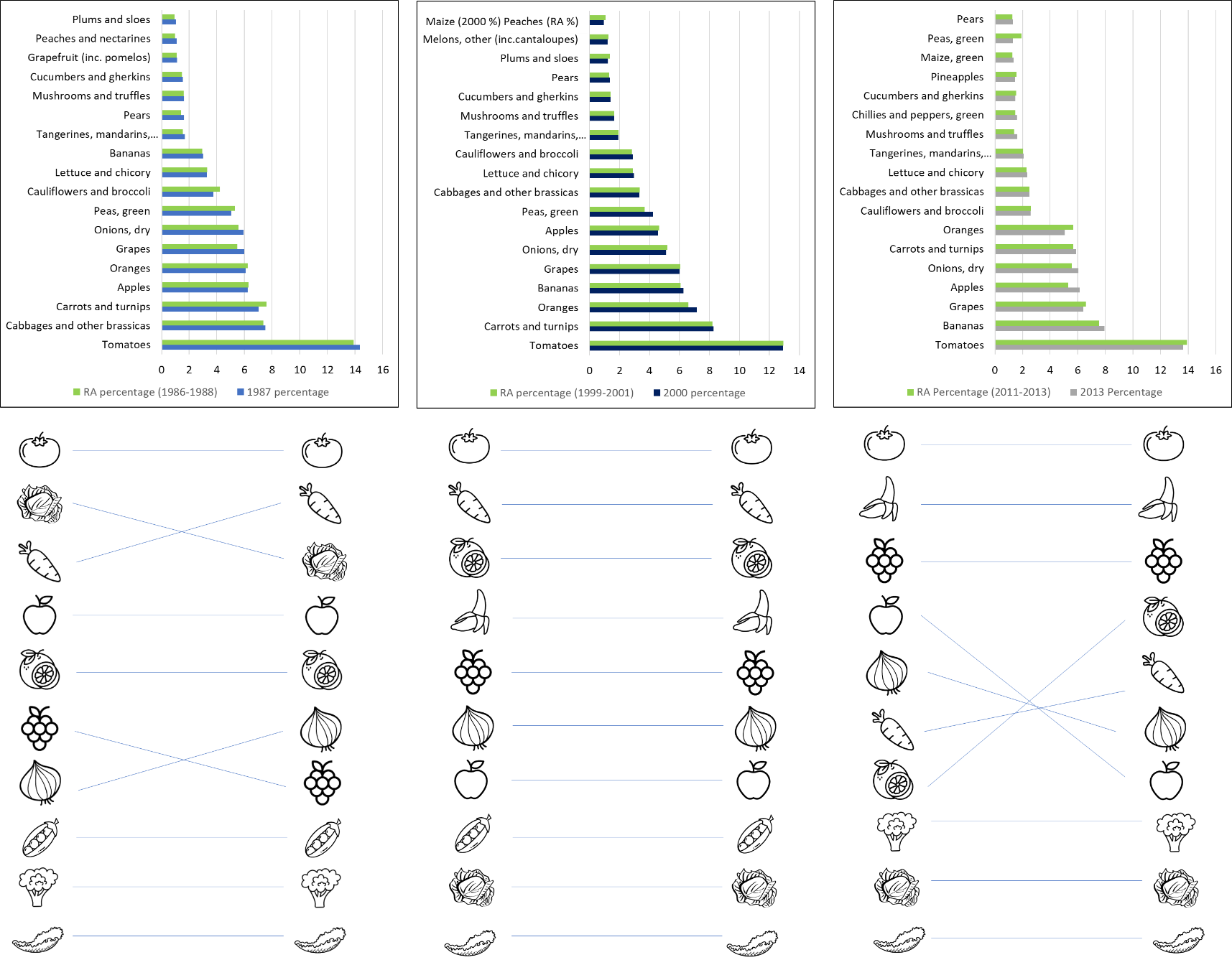


***Supplementary Figure 2. Percent share of all fruit and vegetable supply for years 1987, 2000, and 2013****.*A large number of fruits and vegetables were supplied infrequently and/or in small quantities and were therefore excluded from the analysis. For each year (1987-2013), the top 18 crops were selected for inclusion in the analysis. Supplementary figure 2 shows all crop supply percentages for years 1987, 2000, and 2003. For intermediate years, please contact the author.



**Pineapples**

***Supplementary Figure 3. 2013 Fruit and Vegetable Consumption vs Supply Data for the top 20 crops.*** We compared the FAOSTAT fruit and vegetable *supply data* and the NDNS fruit and vegetable *consumption data* to determine whether the FAOSTAT data could be used as a proxy of fruit and vegetable consumption in the UK. As 2013 was the only year the two datasets overlapped, we have only compared data for that year. Supplementary figure 3 shows the top 20 crops for the supply data and corresponding supply and consumption percentages which indicates that supply data is comparable to consumption data for 2013. The NDNS consumption data included Strawberries, Peaches/Nectarines, Green beans, and Blueberries in their top 20 crops, which were not in the top 20 for the supply data. However, these four fruits and vegetables only accounted for 5% of total consumption in the UK.



***Supplementary Figure 4: Sensitivity analysis comparing a 3-year rolling average to single year measurement.*** *A. The % of total supply for each individual crop; B. Differences between fruit and vegetable supply top 10 comparing single year estimates with 3-year rolling averages.*

# Supplementary Notes

**Supplementary Note 1**

**Cleaning NDNS consumption data to derive grams of primary crop equivalent produced**

We included raw and/or cooked fruits, yellow, green and red vegetables, dried fruit, fruit juices, smoothies, products containing tomato puree and Brassicaceae (mostly leafy vegetables and a few spices).

The clear majority of individuals (98.7%) reported food consumption over four days: records of those with incomplete food diary were corrected by adding their mean consumption per day measured over the recorded period to derive an approximation of their 4-day consumption.

(1)

*Where: c = individual consumption per day; and i = the number of days of dietary data per individual*

For each food item, the “primary fruit or vegetable crop” was determined based on the composition of ingredients. Foods with no clear primary crop were listed as “mixed fruits/vegetables”. Unprocessed food items were included by weight (in grams consumed) of primary crop. The weight (in grams) of primary fruit or vegetable per gram of each dried, juiced, or otherwise processed food item was derived by using Primary Crop Equivalent conversion factors, as defined by Kastner *et al* (2011) (33).

We excluded the category “mixed fruits/vegetables” from the data – which comprised 3.4% of fruit and vegetable consumption in the UK – as this category lacked detail to identify country of origin.

References in Supplementary Information

1. Kastner T, Kastner M, Nonhebel SJEE. Tracing distant environmental impacts of agricultural products from a consumer perspective. 2011;70(6):1032-40.