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UK's fruit and vegetable supply increasingly dependent on imports from climate vulnerable producing countries

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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

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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

- Food and Agriculture Organization of the United Nations. FAOSTAT database. Food and Agriculture Organization of the United Nations, Rome, Italy2013.
- Chen C, Noble I, Hellmann J, Coffee J, Murillo M, Chawla N. University of Notre Dame global adaptation index country index technical report. ND-GAIN: South Bend, IN, USA. 2015.

Figure 4:

- Food and Agriculture Organization of the United Nations. FAOSTAT database. Food and Agriculture Organization of the United Nations, Rome, Italy2013.
- Gassert F, Reig P, Luo T, Maddocks A. A weighted aggregation of spatially distinct hydrological indicators. World Resources Institute. 2013.
- National Centres for Environmental Information - National Oceanic and Admospheric Administration (NOAA). Climate Data Online 2019 [Available from: https://www.ncdc.noaa.gov/cdo-web/datasets.

Figure 5:

- UK Food Standards Agency (FSA), Public Health England (PHE). NDNS: results from years 7 and 8 (combined). Results of the National Diet and Nutrition Survey (NDNS) rolling programme for 2014 to 2015 and 2015 to 2016. London, UK: Crown; 2018.
- 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)

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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.

Introduction

Fruit and vegetables are 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)).

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).

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.

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).

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.

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,

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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:

$$\bar{C}_{\gamma} = \frac{\sum_{i}^{n} \sum_{\vartheta}^{m} (C_{i,\gamma,\vartheta} * E_{\vartheta}) * w_i}{\mathrm{p}} \quad (1)$$

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.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Data availability

Data generated in this study will be made available upon reasonable request through LSHTM Data Compass (https://datacompass.lshtm.ac.uk/ - Scheelbeek, P (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]

Code availability

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

References

1. National Health Service. Health Survey for England 2017. London, UK: 2018.
2. Bates, B, Clifford, R, Collins, D, Cox, L, Davidson, N, Gay, C. et al. on behalf of the Food Standards Agency Northern Ireland & Public Health England. National Diet and Nutrition Survey (NDNS RP): Results for Years 5 to 9 (combined) of the Rolling Programme for Northern Ireland (2012/13 -2016/17) and time trend and income analysis (Years 1 to 9; 2008/09 - 2016/17). Belfast: 2019.
3. 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). 2017
4. Bates B, Lennox A, Prentice A, Bates C, Page P, Nicholson S, et al. on behalf of the Food Standards Agency in Scotland and Public Health England. National Diet and Nutrition Survey Rolling Programme (NDNS RP) Results from Years 1-4 (combined) for Scotland (2008/09-011/12). 2017
5. Institute for Health Metrics and Evaluation (IHME). GBD Compare. Seattle, WA: University of Washington; 2019. [Available from: http://vizhub.healthdata.org/gbd-compare
6. Wang PY, Fang JC, Gao ZH, Zhang C, Xie SY. Higher intake of fruits, vegetables or their fiber reduces the risk of type 2 diabetes: A meta-analysis. Journal of diabetes investigation. 2016; 7(1):56–69.
7. Alissa EM, Ferns GA. Dietary fruits and vegetables and cardiovascular diseases risk. Critical reviews in food science and nutrition. 2017; 57(9):1950–62. [PubMed: 26192884]
8. Aune D, Giovannucci E, Boffetta P, Fadnes LT, Keum N, Norat T, et al. Fruit and vegetable intake and the risk of cardiovascular disease, total cancer and all-cause mortality—a systematic review and dose-response meta-analysis of prospective studies. International journal of epidemiology. 2017; 46(3):1029–56. [PubMed: 28338764]
9. UK Food Standards Agency (FSA), Public Health England (PHE). NDNS: results from years 7 and 8 (combined). Results of the National Diet and Nutrition Survey (NDNS) rolling programme for 2014 to 2015 and 2015 to 2016. London, UK: Crown; 2018.
10. Ministry of Health of Brazil. Dietary guidelines for the Brazilian population. 2nd Edition. Brasília-DF (Brazil): Ministry of Health of Brazil; 2014.

11. Wang, S-s; Lay, S; Yu, H-n; Shen, S-r. Dietary guidelines for Chinese residents (2016) comments and comparisons. Journal of Zhejiang University-SCIENCE B. 2016; 17(9):649–56. [PubMed: 27604857]
12. Willett W, Rockström J, Loken B, Springmann M, Lang T, Vermeulen S, et al. Food in the Anthropocene: the EAT–Lancet Commission on healthy diets from sustainable food systems. The Lancet. 2019; 393(10170):447–92.
13. Public Health England. Helping you eat a healthy, balanced diet. The Eatwell GuideLondon: Public Health England London; 2016.
14. Department for Environment FRA-UG. Statistical data set: Agriculture in the United Kingdom 2018. London: 2019.
15. Wiggins, S, Keats, S, Han, E, Shimokawa, S, Hernández, JV, Claro, RM. The rising cost of a healthy diet: changing relative prices of foods in high-income and emerging economies. Overseas Development Institute; London: 2015.
16. Lobell DB, Schlenker W, Costa-Roberts J. Climate trends and global crop production since 1980. Science. 2011; 333(6042):616–20. [PubMed: 21551030]
17. Wheeler T, Von Braun J. Climate change impacts on global food security. Science. 2013; 341(6145):508–13. [PubMed: 23908229]
18. Asseng S, Ewert F, Martre P, Rötter RP, Lobell DB, Cammarano D, et al. Rising temperatures reduce global wheat production. Nature climate change. 2015; 5(2):143–7.
19. Challinor AJ, Watson J, Lobell DB, Howden S, Smith D, Chhetri N. A meta-analysis of crop yield under climate change and adaptation. Nature Climate Change. 2014; 4(4):287–91.
20. Rosenzweig C, Elliott J, Deryng D, Ruane AC, Müller C, Arneth A, et al. Assessing agricultural risks of climate change in the 21st century in a global gridded crop model intercomparison. Proceedings of the National Academy of Sciences. 2014; 111(9):3268–73.
21. Scheelbeek PF, Bird FA, Tuomisto HL, Green R, Harris FB, Joy EJ, et al. Effect of environmental changes on vegetable and legume yields and nutritional quality. Proceedings of the National Academy of Sciences. 2018; 115(26):6804–9.
22. Alae-Carew C, Nicoleau S, Bird F, Hawkins P, Tuomisto H, Haines A, et al. The impact of environmental changes on the yield and nutritional quality of fruits, nuts and seeds: a systematic review. Environmental Research Letters. 2019
23. Challinor A, Wheeler T, Garforth C, Craufurd P, Kassam A. Assessing the vulnerability of food crop systems in Africa to climate change. Climatic change. 2007; 83(3):381–99.
24. Bita C, Gerats T. Plant tolerance to high temperature in a changing environment: scientific fundamentals and production of heat stress-tolerant crops. Frontiers in plant science. 2013; 4:273. [PubMed: 23914193]
25. Lobell DB, Bänziger M, Magorokosho C, Vivek B. Nonlinear heat effects on African maize as evidenced by historical yield trials. Nature climate change. 2011; 1(1):42–5.
26. Lipper L, Thornton P, Campbell BM, Baedeker T, Braimoh A, Bwalya M, et al. Climate-smart agriculture for food security. Nature climate change. 2014; 4(12):1068–72.
27. Moore FC, Baldos U, Hertel T, Diaz D. New science of climate change impacts on agriculture implies higher social cost of carbon. Nature communications. 2017; 8(1):1–9.
28. Butler, S, Jones, S. Holy guacamole! Avocado fans in UK face further price risesDemand from China and harvest problems in Mexico, Peru and US has led to wholesale prices of fruit surging by more than 50%. The Guardian; 2017.
29. Why is there a vegetable shortage?. London: BBC News; 2017. [Available from: https://www.bbc.co.uk/news/uk-38666752
30. Qureshi ME, Hanjra MA, Ward J. Impact of water scarcity in Australia on global food security in an era of climate change. Food Policy. 2013; 38:136–45.
31. Trostle, R. Global agricultural supply and demand: factors contributing to the recent increase in food commodity prices. rev: Diane Publishing; 2010.
32. Food and Agriculture Organization of the United Nations. FAOSTAT database. Food and Agriculture Organization of the United Nations; Rome, Italy: 2013.

33. Kastner T, Kastner M, Nonhebel SJEE. Tracing distant environmental impacts of agricultural products from a consumer perspective. 2011; 70(6):1032–40.
34. Gobbo L, Khatibzadeh S, Imamura F, Micha R, Shi P, Smith M. Assessing global dietary habits: a comparison of national estimates from the FAO and the Global Dietary Database 1– 4. Am J Clin Nutr. 2015; 101(5):1038–46. [PubMed: 25788002]
35. Chen, C, Noble, I, Hellmann, J, Coffee, J, Murillo, M, Chawla, N. University of Notre Dame global adaptation index country index technical report. ND-GAIN; South Bend, IN, USA: 2015.
36. UK Government. UK horticultural statistics. London: 2019. [Available from: https://www.gov.uk/government/collections/horticultural-statistics
37. Dolan C, Humphrey J. Governance and trade in fresh vegetables: the impact of UK supermarkets on the African horticulture industry. Journal of development studies. 2000; 37(2):147–76.
38. Dolan C, Humphrey J. Changing governance patterns in the trade in fresh vegetables between Africa and the United Kingdom. Environment and planning A. 2004; 36(3):491–509.
39. Edwards-Jones G, Plassmann K, York E, Hounsome B, Jones DL, i Canals LM. Vulnerability of exporting nations to the development of a carbon label in the United Kingdom. environmental science & policy. 2009; 12(4):479–90.
40. Smith, P, Bustamante, M, Ahammad, H, Clark, H, Dong, H, Elsiddig, EA. , et al. Agriculture, forestry and other land use (AFOLU)Climate change 2014: mitigation of climate change Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press; 2014.
41. Gouel, C, Laborde, D. The crucial role of international trade in adaptation to climate change. National Bureau of Economic Research; 2018.
42. Zhao C, Liu B, Piao S, Wang X, Lobell DB, Huang Y, et al. Temperature increase reduces global yields of major crops in four independent estimates. Proceedings of the National Academy of Sciences. 2017; 114(35):9326–31.
43. The Climate Coalition. Recipe for Disaster: How climate change threatens British-grown fruit and veg. Leeds, UK: 2019.
44. Headey D, Fan S. Reflections on the global food crisis: how did it happen? how has it hurt? and how can we prevent the next one? Intl Food Policy Res Inst. 2010
45. Behar, A, Venables, AJ. Transport costs and international tradeA handbook of transport economics. Edward Elgar Publishing; 2011.
46. Seferidi P, Laverty AA, Pearson-Stuttard J, Bandosz P, Collins B, Guzman-Castillo M, et al. Impacts of Brexit on fruit and vegetable intake and cardiovascular disease in England: a modelling study. BMJ open. 2019; 9(1)
47. Hawkesworth S, Dangour AD, Johnston D, Lock K, Poole N, Rushton J, et al. Feeding the world healthily: the challenge of measuring the effects of agriculture on health. Philosophical Transactions of the Royal Society B: Biological Sciences. 2010; 365(1554):3083–97.
48. Hess T, Sutcliffe C. The exposure of a fresh fruit and vegetable supply chain to global water-related risks. Water international. 2018; 43(6):746–61.
49. Poore J, Nemecek T. Reducing food's environmental impacts through producers and consumers. Science. 2018; 360(6392):987–92. [PubMed: 29853680]
50. Bateman IJ, Mace GM. The natural capital framework for sustainably efficient and equitable decision making. Nature Sustainability. 2020:1–8.
51. Gornall J, Betts R, Burke E, Clark R, Camp J, Willett K, et al. Implications of climate change for agricultural productivity in the early twenty-first century. Philosophical Transactions of the Royal Society B: Biological Sciences. 2010; 365(1554):2973–89.
52. National Health Service. 5 A Day: what counts?. 2015. [Available from: https://www.nhs.uk/live-well/eat-well/5-a-day-what-counts/
53. National Association of Cider Makers. NACM Ledbury; UK: 2019. [Available from: https://cideruk.com/
54. Food and Agriculture Organization, International Organisation of Vine and Wine. Non-alcoholic products of the vitivinicultural sector intended for human consumption. Table and Dried Grapes - FAO-OIV Focus 2016Rome: 2016.

55. Kastner T, Nonhebel S. Changes in land requirements for food in the Philippines: A historical analysis. Land Use Policy. 2010; 27(3):853–63.

56. National Centres for Environmental Information - National Oceanic and Admospheric Administration (NOAA). 2019. Climate Data Online. [Available from: https://www.ncdc.noaa.gov/cdoweb/datasets

57. Gassert, F, Reig, P, Luo, T, Maddocks, A. A weighted aggregation of spatially distinct hydrological indicators. World Resources Institute; 2013.

58. Scheelbeek, P. 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: 2020.

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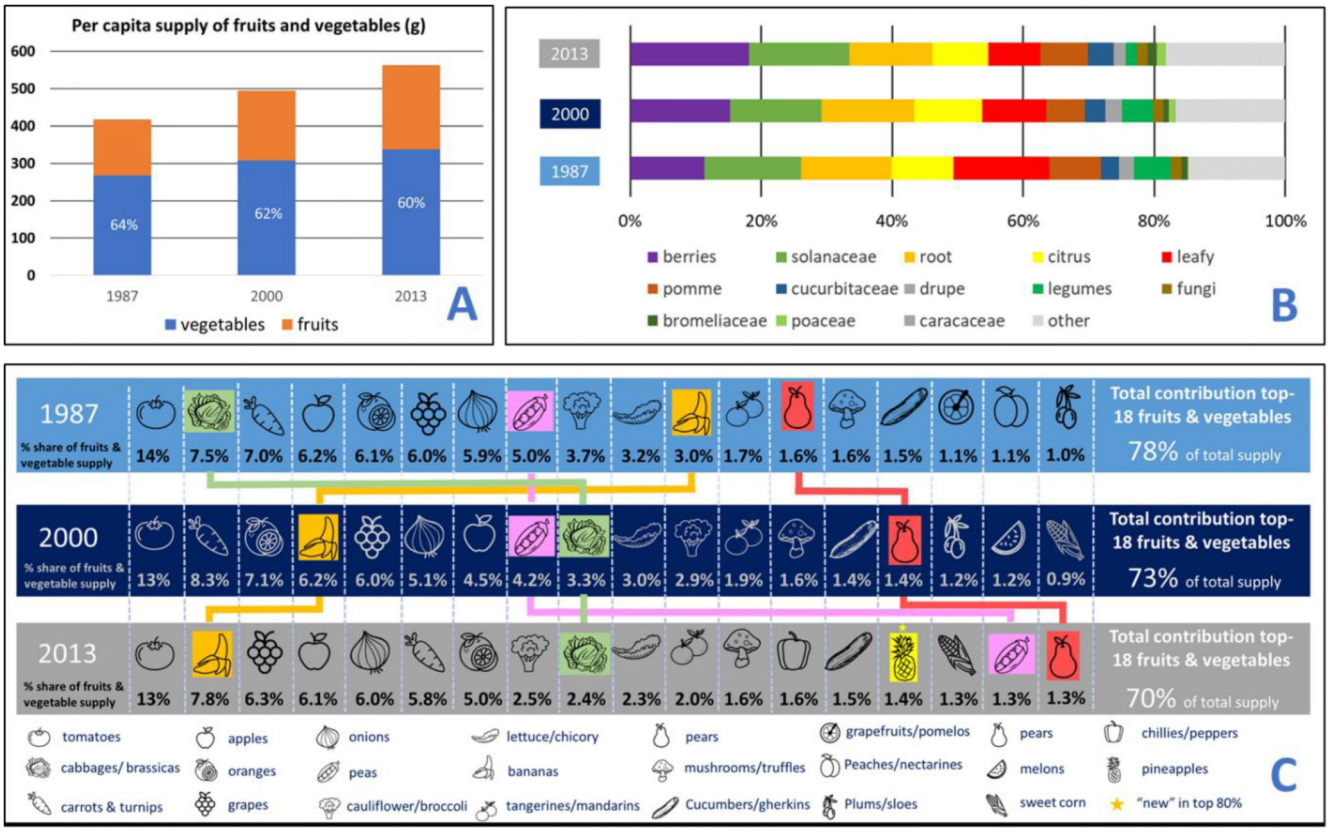

Figure 1. Change in supply of fruit and vegetables in the UK 1987-2013.

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.

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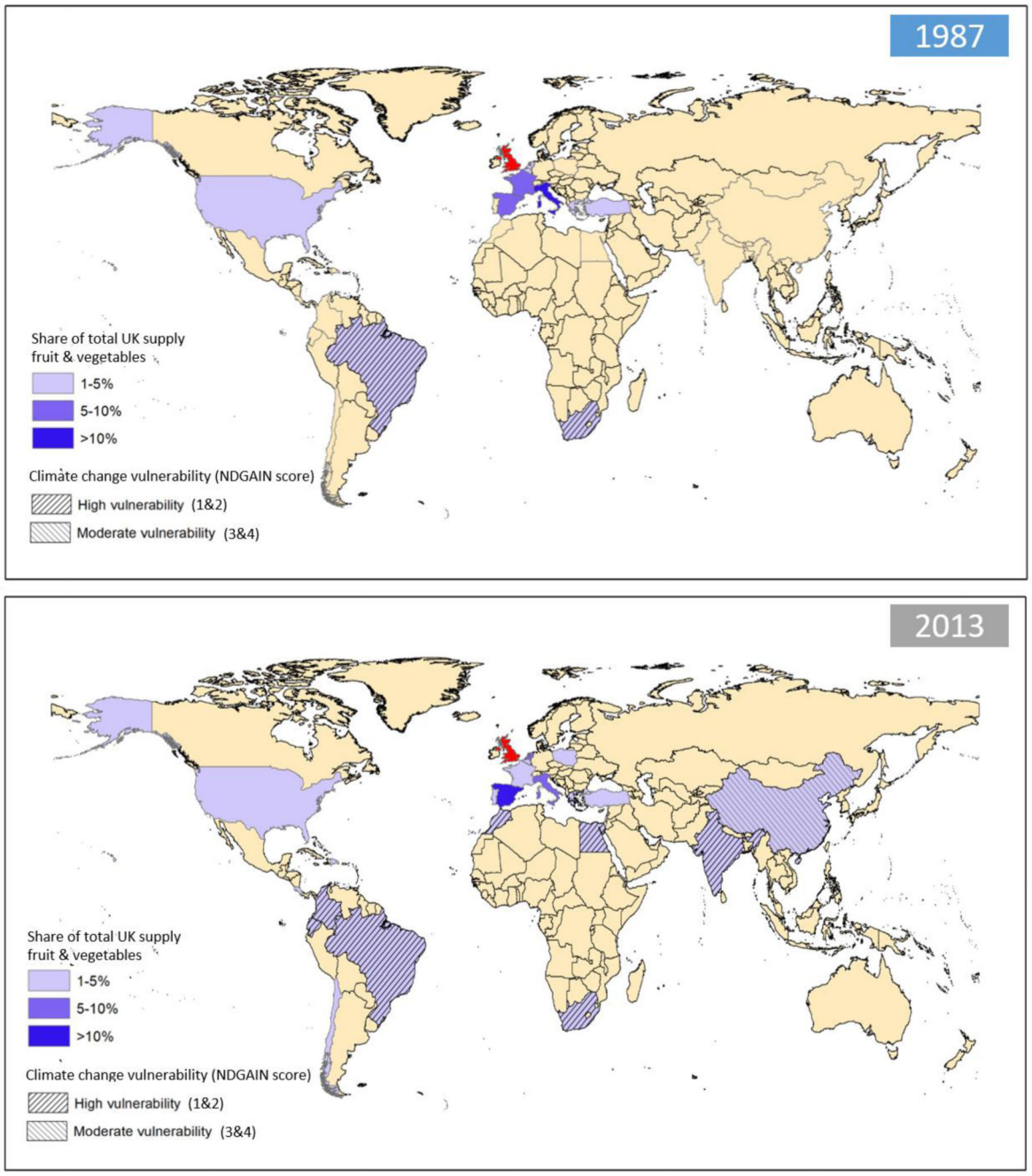

Figure 2. Countries producing at least 1% of UK fruit and vegetable supply in 1987 and 2013
identifying share of supply and Notre Dame Global Adaptation Initiative (NDGAIN) country score category. The NDGAIN categories are quintiles of the NDGAIN scores (1–100) based on indicators of vulnerability to 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).

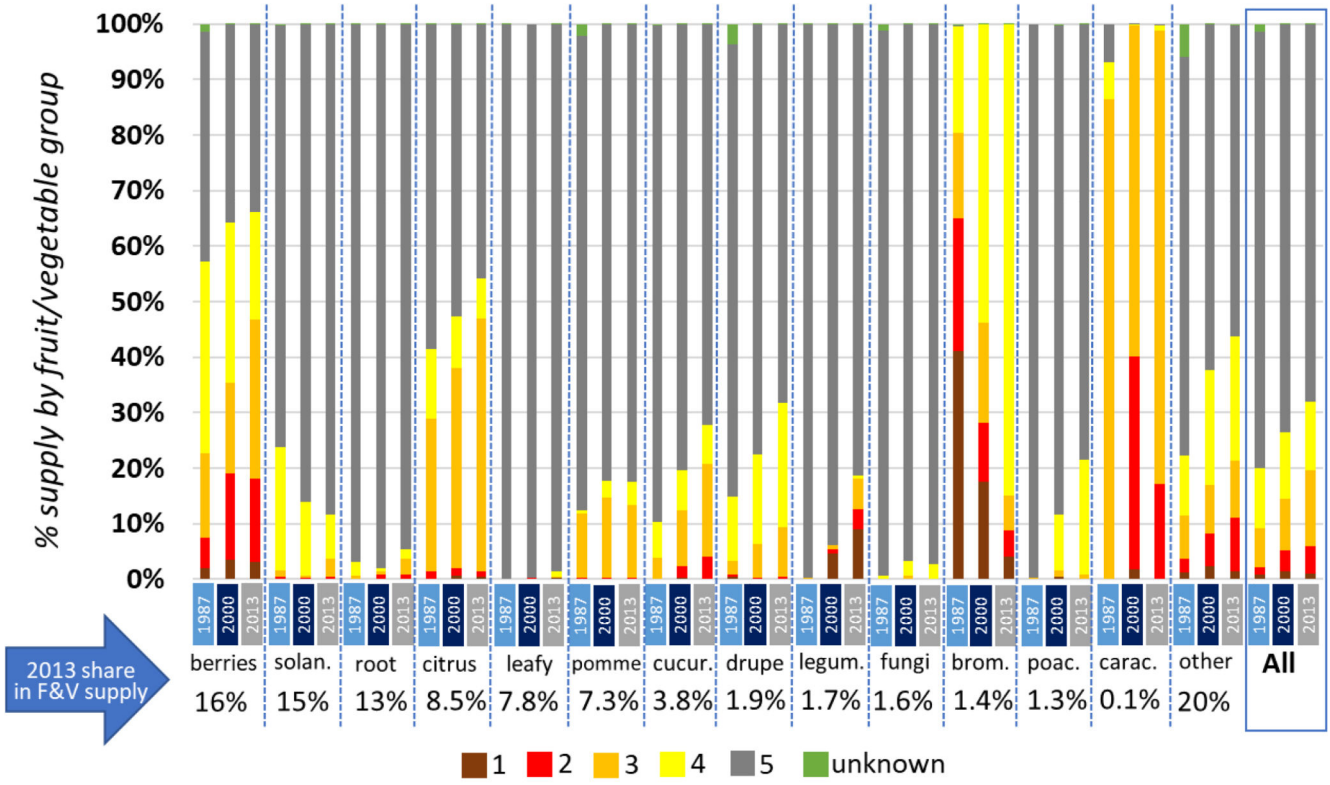

Figure 3. NDGAIN vulnerability index of country of origin of major fruit and vegetable families consumed in the UK.

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.

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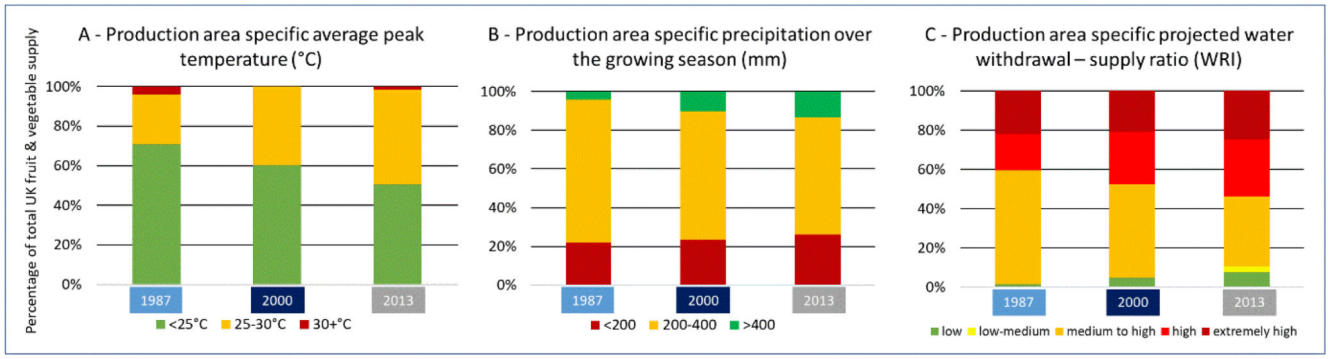

Figure 4. Proportion of fruit and vegetables supplied by production stratified by year for three environmental parameters

A) average peak temperatures (°C) in the growing season; B) precipitation over the growing season; C) projected water stress by 2040 (WRI-index)

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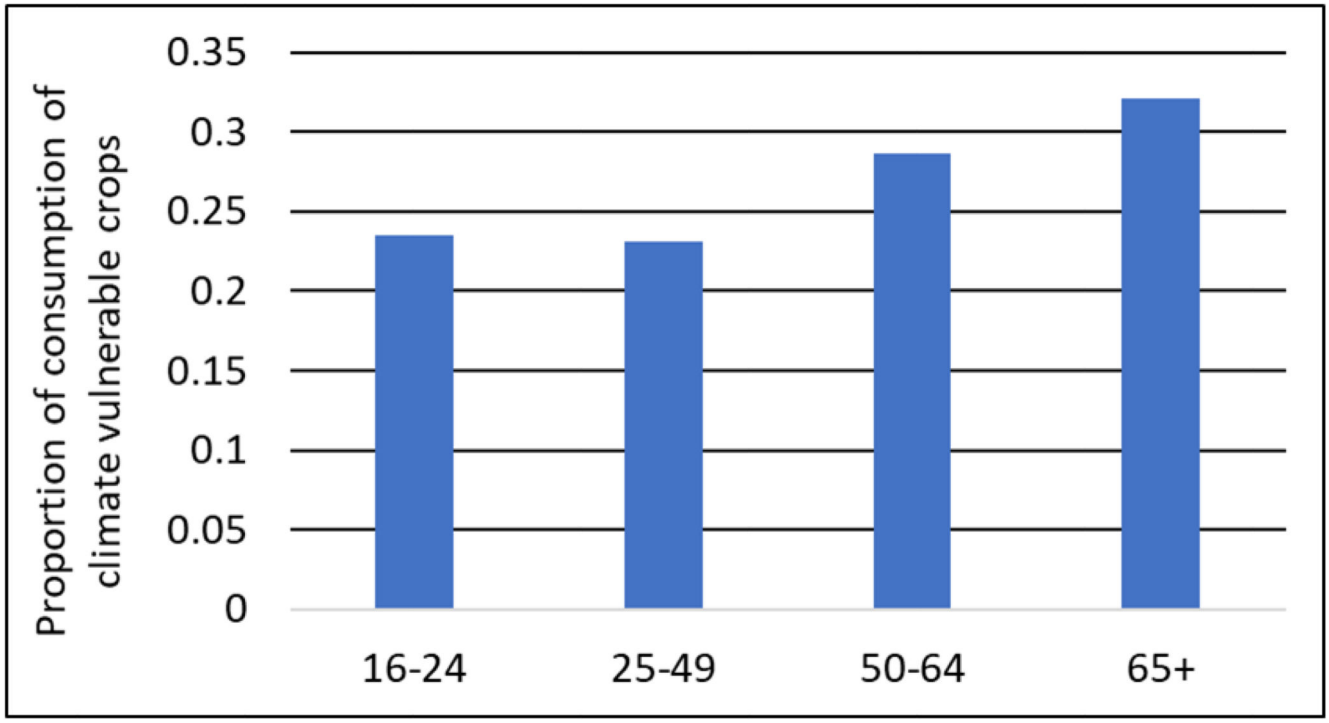

Figure 5. Proportion of consumption of berries and citrus fruits by age group.
Consumption of the two most "vulnerable" crop aggregates (berries and citrus fruits) in total fruit and vegetable consumption - by age group (based on NDNS wave 7&8).

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