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Current and recommended diets in the USA have embedded forced labour risk

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Research on sustainable diets has primarily focused on human and planetary health, neglecting workers in food value chains despite their high global employment and forced labour rates. Combining nationally representative food intake data and forced labour risk data for food commodities, we compared the risk of forced labour embedded in five diets in the USA—current diets, three US-specific recommended dietary patterns and the EAT–*Lancet* Planetary Health Diet. We find that forced labour risk is highest in the Mediterranean-Style and US-Style recommended patterns and lowest in the Planetary Health Diet pattern, with the biggest differences driven by intake of fruit, dairy and red meat. Protein foods account for nearly half of the risk in all patterns, except for the Healthy Vegetarian recommended pattern. These results point to potential synergies and trade-offs between human health, environmental sustainability and social well-being that should be considered in dialogue and action on sustainable diets.

A great transformation of food systems is required to sustainably and equitably meet food needs into the future. Integral to this transformation is dietary change[1]. There is increased attention to promoting diets that are healthy, environmentally friendly[1–3] and affordable[4–9]. However, the implications of these recommended diets for food system workers and labour conditions are unknown[10,11]. This is a yawning gap, given that agri-food supply chains employ 1.23 billion people globally[12].

Truly sustainable diets cannot be actualized without eliminating forced labour in food supply chains. Forced labour is defined by the International Labor Organization as 'all work or service which is exacted from any person under the threat of penalty', which can include violence or intimidation, debt, retention of identity documents or threats[13,14]. Though the prevalence of forced labour has not been estimated for full agri-food supply chains, which encompass multiple sectors, the agriculture, forestry and fishing sector has one of the highest rates of forced labour[15].

In this study, we document the forced labour risk embedded in dietary patterns focusing on both current and recommended diets in the USA. Numerous scholars have documented exploitative labour conditions in the US food system[16–19]. Our prior work focused on assessing risk of forced labour in fruits and vegetables[20] and the land-based US food supply[21], finding that the majority of forced labour risk was domestically sourced and stemmed from a small number of food groups[22]. Here our primary objective is to compare forced labour risk embedded in current and recommended dietary patterns (hereafter referred to as patterns) in the USA and to explore drivers of risk. We map the forced labour risk of current US consumption using nationally representative food intake data from the National Health and Nutrition Examination Survey (NHANES) and compare this to the risk embedded in recommended patterns from the EAT–*Lancet* Commission (Planetary Health Diet) and US government (Healthy US-Style, Healthy Mediterranean and Healthy Vegetarian patterns in the 2020–2025 Dietary Guidelines for Americans). Forced labour risk is quantified in the unit medium risk hours-equivalent (mrh-eq), which combines data on risk and hours worked[20–22]. Risk scores include qualitative risk levels (for example, low, medium) for each commodity and country of origin that have been quantitatively characterized (for example, low = 0.01, medium = 1)

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Table 1 | Dietary pattern intake levels and forced labour risk scores by food group and food subgroup

Food group or food subgroup	Dietary pattern					Forced labour risk score
	CURRENT (*n*=9,759)	HUS	MED	VEG	PHD	
	grams per 2,000 kcal (SE)					mrh-eq per 100 g
Vegetables	**209.9 (4.0)**	**314.1**	**314.1**	**314.1**	**280.0**	–
Dark-green vegetables	19.9 (1.0)	25.3	25.3	25.3	80.0	0.016
Red and orange vegetables	54.1 (1.3)	113.1	113.1	113.1	80.0	0.016
Starchy vegetables	57.7 (1.7)	95.7	95.7	95.7	40.0	0.002
Other vegetables	78.1 (1.9)	80.0	80.0	80.0	80.0	0.015
Fruit	**160.0 (4.4)**	**349.6**	**437.4**	**349.6**	**160.0**	–
Whole fruits, excluding juice	107.0 (3.8)	234.1	291.8	234.1	120.8	0.016
100% fruit juice	52.9 (1.8)	115.5	145.6	115.5	39.2	0.046
Grains	**234.3 (2.0)**	**261.0**	**261.0**	**286.5**	**395.3**	–
Whole grains	45.3 (1.5)	153.0	153.0	178.5	395.3	0.005
Refined grains	189.0 (2.0)	108.0	108.0	108.0	0.0	0.007
Dairy	**206.4 (3.8)**	**447.0**	**298.0**	**447.0**	**200.0**	**0.031**
Protein	**201.3 (2.1)**	**197.8**	**226.8**	**140.4**	**241.6**	–
Eggs	29.8 (0.8)	24.0	24.0	21.4	10.4	0.028
Poultry	53.1 (1.3)	42.3	42.3	0.0	23.2	0.044
Red meat	68.5 (1.4)	54.9	54.9	0.0	11.2	0.185
Seafood	17.7 (0.9)	33.1	62.1	0.0	22.4	0.156
Nuts and seeds	11.2 (0.6)	9.5	9.5	15.0	40.0	0.234
Legumes	20.9 (1.0)	34.0	34.0	104.0	134.4	0.018
Added fats and sugar	**117.0 (1.1)**	**70.3**	**70.3**	**72.1**	**66.2**	–
Unsaturated fat (oil)	27.6 (0.3)	27.0	27.0	27.0	32.0	0.047
Saturated fat	26.0 (0.2)	13.3	13.3	13.9	9.4	0.141
Added sugar	63.6 (1.2)	30.0	30.0	31.3	24.8	0.027

All intake values are presented in grams. The means and standard errors (SE) of intake for the CURRENT pattern were estimated using dietary intake data from NHANES cycles 2015–2016 and 2017–2018. The recommended intake amounts for the remaining patterns were derived from the US Dietary Guidelines for Americans 2020–2025 (HUS, MED, VEG) and the EAT–*Lancet* Commission (PHD). Food-subgroup-level impact factors for forced labour risk (mrh-eq per 100 grams of food) are provided in the final column of the table. Detailed descriptions of each food subgroup are provided in Supplementary Methods. Food groups denoted by bolded font, food subgroups denoted by regular font.

and then multiplied by corresponding labour intensity values to derive mrh-eq (refs. 20,22) (Supplementary Methods).

Results

Forced labour risk was assessed at multiple supply chain stages, including feed, food production (agricultural and fishing) and food processing for over 200 commodities consumed in the USA[22]. These scores were used to calculate weighted averages (Methods) for six food groups and 18 food subgroups corresponding to current and recommended diets for the USA (Table 1). Among the dietary patterns, two of the recommended diets had higher forced labour risk than the current US (CURRENT) dietary pattern (0.610 mrh-eq per capita per day): the Healthy Mediterranean-Style (MED) dietary pattern (0.824 mrh-eq per capita per day) and the Healthy US-Style (HUS) dietary pattern (0.773 mrh-eq per capita per day). Two of the recommended diets had lower forced labour risk than CURRENT: the Healthy Vegetarian (VEG) dietary pattern (0.568 mrh-eq per capita per day) and the Planetary Health Diet (PHD) (0.546 mrh-eq per capita per day) (Table 2 and Fig. 1).

For the MED, HUS and CURRENT patterns, the protein, dairy and fruit food groups were major drivers of risk (Fig. 1). In the MED pattern, protein foods were responsible for 43.1% of total risk (0.355 mrh-eq) (Fig. 2). The MED pattern has the same recommended amounts for protein foods as the HUS pattern, plus an additional 29 grams of seafood per 2,000 kcal per day; it compensates for this increased intake in protein elsewhere in the pattern (that is, less dairy). Protein compensation through the addition of seafood in the MED pattern contributes the greatest proportion of total pattern risk among all food subgroups at 18.9% (Fig. 2). This is due to seafood commodities having more than double the weighted risk (mrh-eq per ton) with feed (Supplementary Table 1) of other meat proteins and being recommended as an additional portion on top of the HUS diet compounding the risk of the MED pattern. Contrastingly, in the CURRENT pattern, red meat had the highest food subgroup contribution at 27.1%. The MED pattern also included the greatest fruit intake of all patterns analysed, which led to the highest absolute risk for fruit among all patterns (0.196 mrh-eq) and a substantial fraction of MED pattern risk at 23.7%. Fruit was also a top contributor to risk for the VEG pattern, reflecting high risk in fruit but also the higher serving size amounts recommended in all of the Dietary Guidelines for Americans patterns, compared to the PHD and current consumption (Table 1).

In the HUS pattern, the dairy food subgroup was the highest contributor to overall risk at 23.7%. The dairy subgroup was also the top contributor to the VEG pattern at 32.3% and a notable contributor to risk in the PHD at 15.0%, despite a much lower recommendation. For the PHD pattern, the protein food group was the leading contributor to risk at a combined 42.6%. In addition to protein foods, the vegetables food group was a major contributor to risk for the PHD and VEG and PHD patterns, at 14.3% and 13.0%, respectively. Across all patterns, the grains food group made the smallest contribution to total forced labour risk (0.022 mrh-eq per capita per day for CURRENT, HUS and MED; 0.024 mrh-eq per capita per day for VEG and 0.029 mrh-eq per capita per day for PHD) (Fig. 1). Added fats and sugar (AFS) also made

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Table 2 | Total forced labour risk by dietary pattern, food group and food subgroup

Food group or food subgroup	Dietary pattern				
	CURRENT	HUS	MED	VEG	PHD
	mrh-eq per capita per day				
Total	**0.610**	**0.773**	**0.824**	**0.568**	**0.546**
Vegetables	**0.051**	**0.074**	**0.074**	**0.074**	**0.078**
Dark-green vegetables	0.007	0.009	0.009	0.009	0.027
Red and orange vegetables	0.016	0.034	0.034	0.034	0.024
Starchy vegetables	0.005	0.009	0.009	0.009	0.004
Other vegetables	0.023	0.023	0.023	0.023	0.023
Fruit	**0.072**	**0.156**	**0.196**	**0.156**	**0.070**
Whole fruits, excluding juice	0.044	0.095	0.119	0.095	0.049
100% fruit juice	0.028	0.061	0.077	0.061	0.021
Grains	**0.022**	**0.022**	**0.022**	**0.024**	**0.029**
Whole grains	0.003	0.011	0.011	0.013	0.029
Refined grains	0.018	0.010	0.010	0.010	–
Dairy	**0.085**	**0.183**	**0.122**	**0.183**	**0.082**
Protein	**0.287**	**0.282**	**0.355**	**0.074**	**0.239**
Eggs	0.013	0.010	0.010	0.009	0.004
Poultry	0.029	0.023	0.023	–	0.013
Red meat	0.165	0.133	0.133	–	0.027
Seafood	0.045	0.083	0.156	–	0.056
Nuts and seeds	0.030	0.026	0.026	0.041	0.108
Legumes	0.005	0.008	0.008	0.024	0.031
Added fats and sugar	**0.095**	**0.055**	**0.055**	**0.057**	**0.048**
Unsaturated fat (oil)	0.016	0.015	0.015	0.015	0.018
Saturated fat	0.053	0.027	0.027	0.028	0.019
Added sugar	0.026	0.012	0.012	0.013	0.010

a minor contribution to risk across all patterns, with the exception of the CURRENT diet (0.095 mrh-eq) at 15.6% of the total risk of forced labour in that pattern.

The protein food group accounted for nearly half of the risk in all patterns, except for VEG. Figure 3 shows the intake distribution in grams of the six protein subgroups (eggs, poultry, red meat, seafood, nuts and seeds and legumes) compared to the total forced labour risk distribution of the six protein subgroups for all five dietary patterns. Comparing the relative amounts consumed (or recommended) against risk allows us to examine where risk is disproportionately high in certain patterns. This highlights what is driving the resulting risk: amounts consumed or recommended, high embedded risk or both. In the PHD and VEG patterns, the nuts and seeds forced labour risk contribution is around two to five times larger than the nuts and seeds intake contribution, indicating that the per unit forced labour risk of nuts and seeds is driving that risk hotspot (Fig. 3). For the CURRENT, HUS, MED and PHD patterns, the red meat risk contribution is over 1.5 times greater than red meat intake contribution, indicating disproportionately high forced labour risk compared to intake but less stark than that of nuts and seeds.

Commodities driving risk in the food subgroups

Figure 4 shows the percentage contribution to risk from the commodities included in each food subgroup. The consumption-weighted average scores for the 18 food subgroups are shown in the final column of Table 1. Total risk for each food subgroup is a function of commodity-level consumption, inedible amount, wasted amount and risk level and can be primarily driven by one—or multiple—of these variables. Extended Data Fig. 1 shows the distribution of NHANES participants' daily food commodity intake by food subgroup. Comparing the values in Fig. 4 and Extended Data Fig. 1 allows us to examine what factor or factors are primarily driving risk in each food subgroup. For seven of the 18 (38.9%) food subgroups, the forced labour risk from only one commodity contributed to more than half of the subgroup-level risk. For example, asparagus contributed to 54.6% of the subgroup-level dark-green vegetable risk, despite accounting for only 6.8% of intake (Extended Data Fig. 1). Similarly, cashews contributed to 73.2% of the total risk in nuts and seeds but only 10.8% of intake (Extended Data Figs. 1–3). Other food subgroups had a more uniform distribution of risk from commodities but did show hotspots. Subgroup-level risk for whole fruit and other vegetables did not have a commodity that contributed to more than one quarter (25.0%) of the subgroup-level risk. However, avocados represented only 4.0% of whole fruit intake and contributed 22.1% of whole fruit's total risk.

Sensitivity analyses

To assess the robustness of our results, we performed sensitivity analyses and assessed whether the relationships between the patterns changed using ranks. The total amount of forced labour risk for the five patterns was ranked from 1 (lowest total risk) to 5 (highest total risk). In our main analyses (that is, the baseline scenario), the PHD pattern had the lowest total forced labour risk (0.546 mrh-eq per capita per day) and was assigned Rank 1, and the MED pattern had the highest total forced labour risk (0.824 mrh-eq per capita per day) and was assigned Rank 5 (Fig. 5). Because commodity risk scores vary widely within food subgroups, we replaced the weighted average subgroup-level risk scores with the lowest and highest corresponding commodity-level risk scores (Supplementary Table 2), rerunning the original analysis and recalculating the ranks (Methods). Overall, approximately 23 of the total 36 scenarios (63.9%) resulted in the same pattern ranking as the baseline scenario. There were no scenarios where the rank for all five patterns changed. It is important to note that pushing individual food subgroup scores to minimum or maximum risk values did change the magnitude of risk in the patterns, in some cases dramatically. For example, forced labour risk for the VEG pattern ranged from 0.499 to 4.615 mrh-eq per capita per day across scenarios; for the highest value, the rank of the VEG pattern also changed, but only from 2 to 3 Rank also changed for the CURRENT pattern at its lowest and highest values. However, for the PHD, HUS and MED patterns, the rank did not change except in the scenarios where the patterns were at their lowest and highest values. Additional sensitivity analyses were run with and without risk in feed incorporated in the patterns (Extended Data Figs. 2 and 3 and Supplementary Methods).

Discussion

We presented an estimation of the risk of forced labour embedded in dietary patterns. This work represents a starting point to inform dietary transitions that promote equity and justice alongside health, economic and ecological sustainability considerations.

Focusing on the USA, we found that healthy diets could have higher or lower risk of forced labour compared to current consumption, depending on how those healthy diets are operationalized. Notably, two of the three patterns included in the 2020–2025 Dietary Guidelines for Americans—the Healthy Mediterranean-Style (MED) and Healthy US-Style (HUS) pattern—had higher risk of forced labour than current US intake, findings that were robust even when the risk embedded in animal feed was removed entirely from the analysis. Whereas attention has been drawn previously to the potential environmental impacts of these patterns[23], here we highlight potential social consequences

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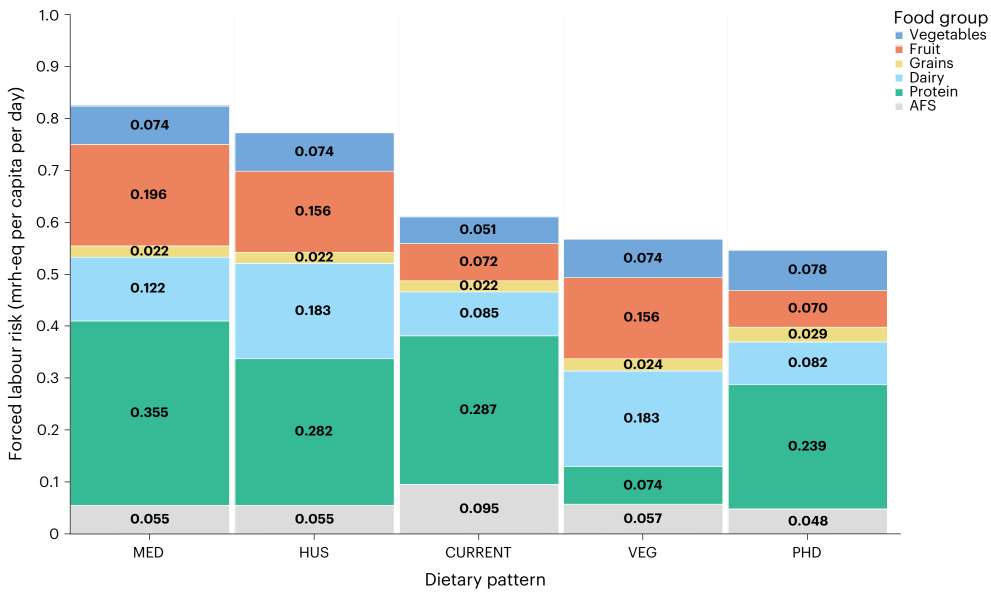

Fig. 1 | Total forced labour risk in each dietary pattern by major food group. Each vertical bar represents the total amount of forced labour risk, measured in the unit mrh-eq, for the five dietary patterns. The different colour segments correspond to the amounts of risk that are attributable to each of the six food groups. AFS, added fats and sugar.

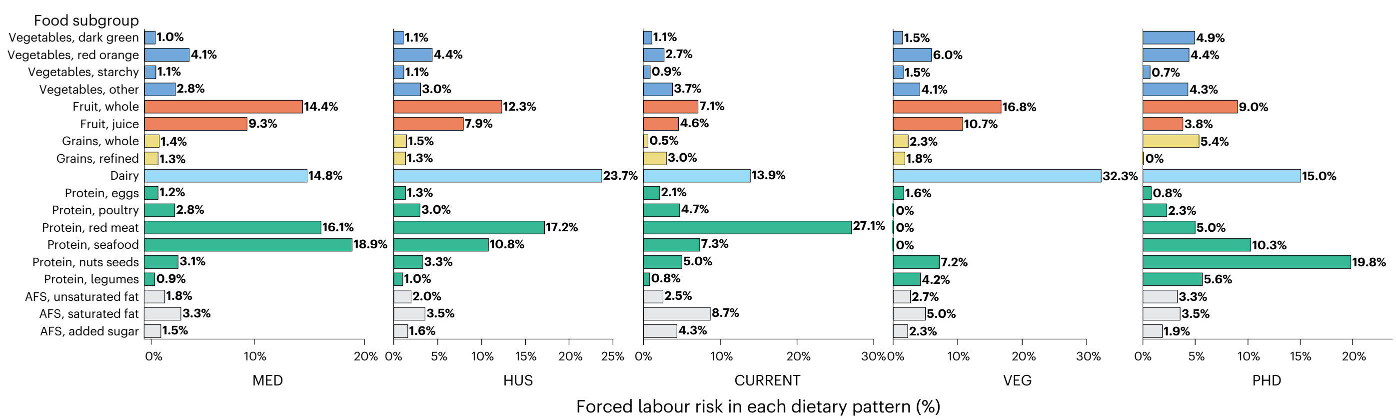

Fig. 2 | Total forced labour risk in each dietary pattern by food subgroup. Each horizontal bar represents the column percentage of forced labour risk, broken down by 18 food subgroups, for the five dietary patterns. The percentages for each pattern sum to approximately 100%. The different colour segments correspond to the amounts of risk that are attributable to each of the six food groups. AFS, added fats and sugar.

of healthy diets, focusing on the risk of forced labour. It is important to underscore that the MED pattern in the Dietary Guidelines for Americans probably diverges from other Mediterranean diet archetypes, where meat, poultry, eggs and dairy are de-emphasized relative to seafood[24].

The PHD, by contrast, had the lowest risk at baseline and in the majority of sensitivity analyses. This pattern was developed as a global archetype to promote human health within several planetary boundaries[1], though it may lead to nutritional deficiencies in certain subpopulations for specific nutrients of concern including iron, zinc, calcium and vitamin B12[25]. That said, this pattern may present a win–win–win opportunity for health, ecosystems and labour in the US context, potentially reducing risk of forced labour relative to current consumption, but more work is needed to address the underlying causes of forced labour[26]. At the same time, there were examples of increased forced labour risk relative to current and recommended consumption in the sensitivity analyses. For instance, changing the nuts and seeds risk score to the highest risk commodity—shelled cashews—resulted in forced labour risk much greater than current intake and all other recommended patterns suggesting specific commodities may require enhanced efforts to raise working standards through investment from sourcing companies (for example, worker leadership, transparency and timescales)[27]. This underscores the imperative to reduce risk upstream in the supply chains that bring healthy foods to the table.

Our analysis focused on US food consumption, which is underpinned by complex food supply chains that rely on domestic production and imports[22]. The forced labour risk embedded in these commodities, food groups and diets would not be the same for other countries. The magnitude and distribution of forced labour risk in other countries' food supplies is to date unknown and an important area of future research that could be undertaken by replicating our approach. Efforts to address forced labour should be tailored to the specific production practices used and include workers operating in the country where the intervention is developed.

The data used in this study pose some limitations. First, they do not reflect current trade policy (for example, reciprocal and flat-rate US tariffs[28]), which is likely to put pressure on insecure workers[29] and food security[30]; nor do they reflect the implications on trade and diets

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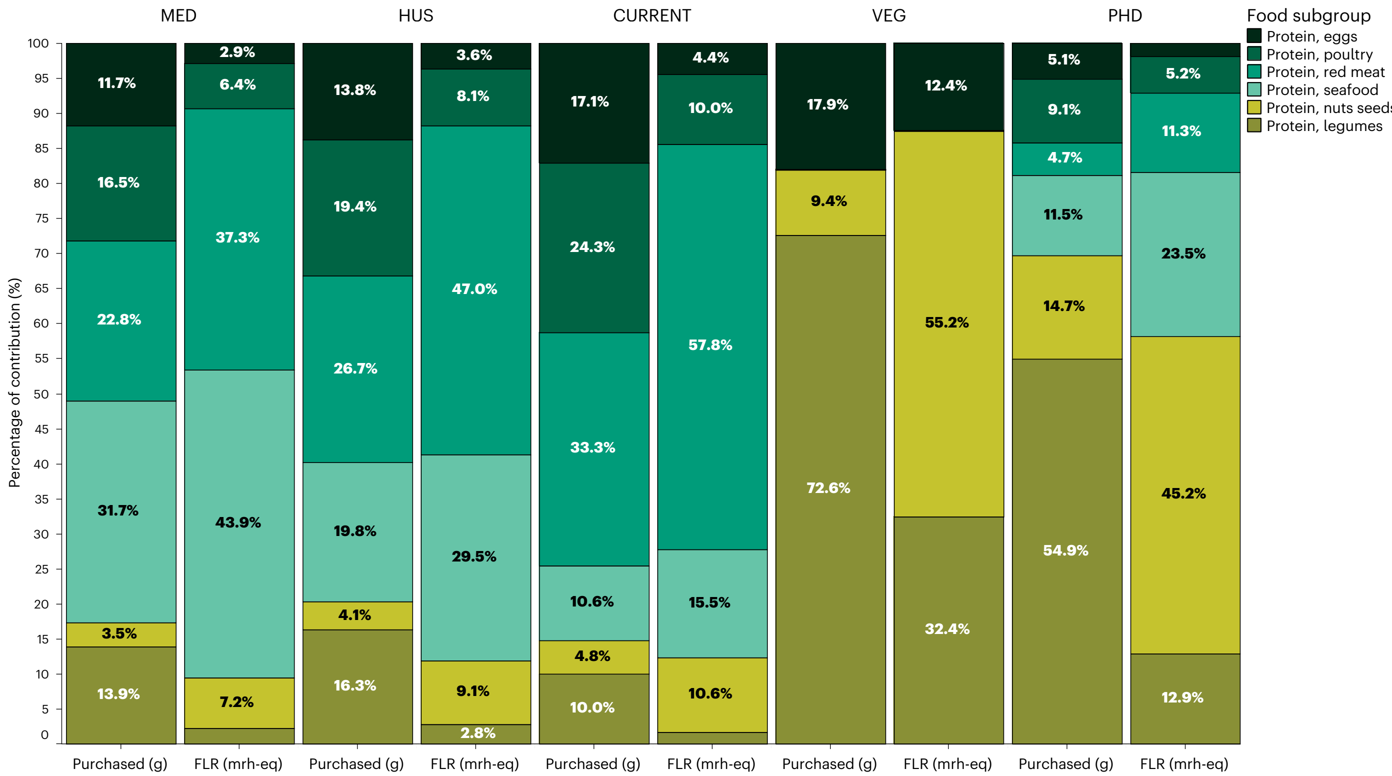

Fig. 3 | Protein subgroup contributions to amount of food purchased and total forced labour risk across all dietary patterns. Each of the five dietary patterns have two associated side-by-side bars shown in the figure. The first, leftmost vertical bar labelled 'Purchased (g)' shows the percent distribution of daily purchased food, measured in grams, split up by protein subgroup (eggs, poultry, red meat, seafood, nuts and seeds and legumes), for the MED pattern. The following vertical bar labelled 'FLR (mrh-eq)' shows the percent distribution of daily forced labour risk, measured in mrh-eq, split up by protein subgroup, for the MED pattern. The following eight vertical bars are associated with the HUS, CURRENT, VEG and PHD patterns, respectively. Contributions less than 2.5% of the total in each bar are not labelled.

that have arisen due to the pandemic[31], rising inflation[32] and shifting ideology at the Department for Health and Human Services[33], which may have an impact on dietary guidelines and consumer choices. Second, our data are cross-sectional and give an assessment of risk at a point in time, whereas dietary changes are likely to occur over long periods of time. Longitudinal data monitoring systems are needed to continuously assess evolving and shifting risk and working conditions and knock-on effects that may occur. For instance, the social impacts of increased avocado production in Mexico for global consumption (characterized in our work as 'very high risk')[22] have been widely documented[34–38]. Third, Magrach and Sanz[38] exposed environmental and social consequences of increased demand for 'superfoods', such as cacao, coconuts, avocado, quinoa, almonds and açai, which have led to changes from traditional production methods to monoculture, affecting the livelihoods of local communities[38]. Macro-economic benefits are sometimes coupled with negative social consequences such as increased inequity, the growing involvement of criminal organizations and the use of forced labour in farming[35]. Understanding the multi-factorial social implications warrants further study and transparency in mandated reporting that identify transgressions should be made public to inform food systems transformation efforts.

Likewise, our analysis is not without limitations. Part of forced labour risk estimation relies on secondary data, which is based on assumptions to fill missing data, increasing uncertainties in the results; these uncertainties have been exposed in the data-quality assessment by Blackstone et al.[22] and should be considered when interpreting the results presented here. Likewise, despite our efforts to map the global feed supply chain through multiple datasets, the complexity and lack of data necessitated a streamlined approach (Methods), which generated uncertainties in the analysis. Similarly, incorporating risk in seafood in this analysis marks a substantial advancement, which was made possible by overcoming previous data limitations (Methods). However, the absence of granular data on gear type, which is directly related to working hours and the forced labour indicator of excessive overtime, means seafood risk scores should be interpreted with caution. Finally, while using NHANES to estimate the CURRENT pattern means the most representative data on US food intake available were used, this also led to a limitation: the dataset available to map forced labour risk scores to NHANES, the Food Commodity Intake Database[39], separates complex foods into its constituent basic commodities (for example, dairy products are separated into milk fat, milk non-fat solids and milk water), implying that risk embedded in processing was sometimes excluded. This underestimation is probably small, however, as we previously found that 85% of risk in the US food supply is attributable to agriculture[22].

Typically, modelling focused on the sustainability implications of dietary patterns point to the promise of shifting country-level food-based dietary guidelines to reduce impacts (that is, by recommending less meat intake)[23,40]. In the USA, such changes have proved challenging to date. Political will aside, for the phenomenon of forced labour, changing recommendations for food groups and subgroups will not solve the underlying structural and governance problems that perpetuate forced labour and other forms of labour exploitation in food supply chains[41].

One promising area of demand-side solutions—which are necessary for policymakers to take action on as identified by our results—lies in changing public and institutional food-procurement policies. The Dietary Guidelines for Americans shape federal procurement and feeding programmes, the largest examples of which are the National School Lunch and Breakfast programmes. By law, the nutrition standards

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Fig. 4 | Distribution of commodity-level risk by food subgroup. All data are presented as percentages. The vertical bars in the top row show the distribution of forced labour risk for vegetable and fruit subgroups. The vertical bars in the middle row show the risk distribution for animal-based food subgroups including meats, seafood, eggs, saturated fat and dairy. The vertical bars in the bottom row show the risk distribution for plant-based food subgroups including nuts and seeds, legumes, grains, unsaturated fats and added sugars. Contributions less than 2.5% of the total in each bar are not labelled. AFS, added fats and sugar. w/o, without.

outlined in the Guidelines need to be upheld in these programmes to promote healthy lifestyles among school-aged children (that is, limits to added sugar and sodium in foods provided, availability of fat-free milk, frequency of whole grains served throughout the week)[42,43]. Though nascent, there is also movement towards integrating environmental considerations in public procurement. For example, 16 cities globally, including New York City and Los Angeles, have committed to adopting the PHD in their food policies, public procurement and school meal programmes[44]. Re-emphasizing forced labour risk in public procurement and enforcing penalties for suppliers with non-compliance should be enacted[45].

Whereas this analysis suggests that the PHD may also mitigate some forced labour risks, public and institutional procurement should also require proactive efforts to identify, mitigate, remedy and ultimately eliminate and prevent a range of labour and human rights abuses, in food supply chains[46]. These steps would also prepare entities to align their procurement practices in advance with globally proliferating legally and financially binding human rights due diligence directives, which are expected to impact more than 10,000 US businesses—a number that is likely to continue to increase[47]. However, to do so will require companies and institutions to have meaningful, proactive, continuous and direct worker engagement throughout their supply chains[48]. This could be done by moving beyond respecting the right to freedom of association to creating an enabling environment for unionization efforts or engagement with other evidence-based legally binding worker-driven solutions, such as the worker-driven social responsibility model[49]. Encouraging investment into supply chain improvements (for example, through worker-led compliance initiatives such as the Fair Food Program[50]) rather than transference to other suppliers should also be encouraged for USA-based and overseas value chains to avoid the 'mobility of risk' being displaced to other regions and commodities with limited oversight, rather than addressing forced labour as it is identified and remedying those issues[20,22].

At the same time, a critical aspect of procurement and intervention policy is cost-effectiveness; future research is needed to understand the cost implications of such programmes, alongside the labour, environmental and health implications. More broadly, whether eliminating forced labour would leave consumers, especially those with low incomes, worse off economically is unclear, given the complex systems involved. For example, limited evidence suggests that increases in agricultural wages would have minimal effects on food prices in the USA[51]. Whereas adequate earnings are only one aspect of decent work (the antithesis of forced labour), increased wages for food system workers could increase their purchasing power, thus improving affordability for large, low-income subpopulations[11]. Further, an International Labour Organization analysis found that eradicating forced labour would increase

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Scenario	PHD	VEG	CURRENT	HUS	MED
	Dietary pattern				
Baseline	0.546	0.568	0.610	0.773	0.824
MIN: Vegetables, dark green	0.529	0.562	0.606	0.767	0.818
MIN: Vegetables, red orange	0.525	0.539	0.596	0.744	0.795
MIN: Vegetables, starchy	0.543	0.561	0.606	0.766	0.817
MIN: Vegetables, other	0.532	0.553	0.596	0.759	0.810
MIN: Fruit, whole	0.511	0.499	0.579	0.704	0.739
MIN: Fruit, juice	0.528	0.515	0.586	0.720	0.757
MIN: Grains, whole	0.521	0.556	0.607	0.763	0.814
MIN: Grains, refined	0.546	0.562	0.601	0.767	0.818
MIN: Dairy	0.538	0.549	0.602	0.754	0.811
MIN: Protein, eggs	0.546	0.568	0.610	0.773	0.824
MIN: Protein, poultry	0.543	0.568	0.604	0.768	0.819
MIN: Protein, red meat	0.524	0.568	0.473	0.663	0.714
MIN: Protein, seafood	0.498	0.568	0.572	0.702	0.691
MIN: Protein, nuts seeds	0.441	0.529	0.581	0.748	0.799
MIN: Protein, legumes	0.519	0.547	0.606	0.766	0.817
MIN: AFS, unsaturated fat	0.530	0.555	0.597	0.760	0.811
MIN: AFS, saturated fat	0.531	0.546	0.570	0.752	0.803
MIN: AFS, added sugar	0.540	0.560	0.594	0.765	0.816
MAX: Vegetables, dark green	0.901	0.680	0.699	0.885	0.936
MAX: Vegetables, red orange	0.602	0.647	0.648	0.853	0.904
MAX: Vegetables, starchy	2.237	4.615	3.050	4.820	4.871
MAX: Vegetables, other	1.365	1.387	1.410	1.592	1.643
MAX: Fruit, whole	0.988	1.425	1.002	1.630	1.893
MAX: Fruit, juice	0.662	0.908	0.766	1.113	1.253
MAX: Grains, whole	1.192	0.860	0.684	1.023	1.074
MAX: Grains, refined	0.546	0.744	0.919	0.949	1.000
MAX: Dairy	0.826	1.194	0.900	1.399	1.242
MAX: Protein, eggs	0.558	0.592	0.644	0.800	0.851
MAX: Protein, poultry	0.546	0.568	0.611	0.774	0.825
MAX: Protein, red meat	0.554	0.568	0.661	0.814	0.865
MAX: Protein, seafood	0.711	0.568	0.741	1.017	1.282
MAX: Protein, nuts seeds	1.188	0.809	0.790	0.925	0.976
MAX: Protein, legumes	0.592	0.603	0.617	0.784	0.835
MAX: AFS, unsaturated fat	0.843	0.818	0.866	1.023	1.075
MAX: AFS, saturated fat	0.560	0.588	0.648	0.792	0.843
MAX: AFS, added sugar	0.580	0.611	0.697	0.814	0.865

Rank 1 – 5

Fig. 5 | Sensitivity analysis results for the minimum and maximum scenarios. The figure's left-hand column describes the 37 scenarios that were assessed: baseline (that is, original analysis), 18 scenarios where the subgroup-level risk scores were replaced with the lowest commodity-level risk score ('MIN') and 18 scenarios where the subgroup-level risk scores were replaced with the highest commodity-level risk score ('MAX'). The following five dietary pattern columns are sorted based on the results from the baseline scenario, where PHD was Rank 1 (lowest total risk), VEG was Rank 2, CURRENT was Rank 3, HUS was Rank 4 and MED was Rank 5 (highest total risk). In the figure, the lightest colour (white) represents Rank 1, whereas the darkest colour (dark blue) represents Rank 5. Ranks 2–4 are represented by light, medium and medium-dark blue colours.

economic growth and purchasing power across society[52]. Whereas concerns about increased costs merit further research, they should not deter action on eradicating forced labour in food supply chains.

The past several years saw tremendous momentum in developing evidence to support transitions towards healthy diets from sustainable food systems as complex adaptive systems. Our analysis shows that the human cost of bringing these diets to the table is steep indeed. Eliminating forced labour in food supply chains must be a starting point, but it cannot be the end. Ensuring decent work for and in collaboration with the 'hands that feed us' is necessary to achieve truly sustainable diets[53,54].

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Methods

This cross-sectional study quantitatively assessed the risk of forced labour embedded in (1) current US diets, (2) three dietary patterns recommended by the Dietary Guidelines for Americans and (3) the Planetary Health Diet recommended by the EAT–*Lancet* Commission. All data were managed and analysed in R (v.4.4.0), Microsoft Excel (v.16.83), TableauPrep (v.2024.1) and TableauDesktop (v.2023.2.0).

Data

Risk of forced labour. Forced labour risk per ton of food product for 147 food products in the US land-based food supply was retrieved from Blackstone et al.[22]. The risk scores were calculated as a function of characterized risk and worker hours (Supplementary Methods). In summary, we integrated several datasets (supply, prices, characterized risk and working hours) to estimate the risk associated with each commodity–country, multiplying the characterization risk of forced labour by labour intensity and the supply share at the country level (imported or domestically produced). For the risk characterization process, data for Step 1 (commodity–country risk) and Step 2 (sector–country risk) were updated with new governmental sources[55–57] for country–commodity and country–sector risks using the 2023 report following the protocols established in Blackstone et al.[22].

Additionally, we applied the same methodology described above to calculate forced labour risk scores for 48 food products in the US sea-based food supply (that is, seafood), except we used food balance sheets of fish and fishery products as the main data source for estimating the US supply via FishStatJ software (Global Fish Trade Statistics v.2022.1.0).

We also incorporated livestock and seafood feed data to more accurately represent the embedded risk for animal products, including cow's milk, chicken eggs, sheep meat, cattle meat, chicken meat, pig meat and aquaculture. For livestock, we collected feed requirements from the Global Livestock Environmental Assessment Model, including feed commodities and feed conversion rates by animal, region and system (that is, feedlot, grassland based). Additional data processing was necessary to generate risk scores for feed items that were not in our original risk database (for example, byproducts) (Supplementary Methods). Next, we assigned the risk of forced labour to each feed item and multiplied it by the amount required to obtain one unit of animal product. Forced labour risk scores were obtained from Blackstone et al.[22] considering a global average risk for feed coming from outside the USA, and US forced labour risk for domestic production. For aquaculture, we integrated feed requirements from multiple sources[58–60], standardized each feed item into primary commodities weights and assigned forced labour risk similar to the livestock method (Supplementary Tables 3 and 4).

Lastly, the additional risk attributable to animal feed was added to the original risk scores for the 58 animal products and byproducts to create new scores that incorporate the risk from both the food product and their corresponding animal feed. A detailed description of the methodology used to calculate the forced labour risk scores is provided in Supplementary Methods. The final scores utilized in the analysis are available in the final column of Table 1.

Current and recommended dietary patterns. Dietary intake of 18 food subgroups (that is, the CURRENT pattern) was estimated using nationally representative data from two recent waves of the National Health and Nutrition Examination Survey (NHANES) (2015–2016 and 2017–2018)[61,62] (n = 9,759), accounting for complex survey design and sampling weights to be representative of the US population aged 20 years or older. NHANES participants whose dietary recall status was labelled as either 'not reliable or not met the minimum criteria' or 'not done' were removed from the analytic sample. Per capita daily average intake was estimated by averaging up to two days of 24-hour dietary recalls from each participant, and intake was adjusted for energy intake using the residual method to reduce measurement error. Of the 9,759 participants in the analytic sample, 1,416 (14.5%) had one day of dietary recall and 8,343 (85.5%) had two days of dietary recall.

The 18 food subgroups included dark-green vegetables, red and orange vegetables, starchy vegetables, other vegetables, whole fruits (excluding juice), 100% fruit juice, whole grains, refined grains, dairy, eggs, poultry, red meat, seafood, nuts and seeds, legumes, unsaturated fat (oil), saturated fat and added sugar.

Four recommended dietary patterns at the 2,000 kcal d^{-1} level were selected to compare to the current US adult dietary pattern. These include three patterns from the 2020–2025 Dietary Guidelines for Americans: the Healthy US-Style Pattern (HUS), the Healthy Vegetarian Pattern (VEG) and the Healthy Mediterranean-Style Pattern (MED)[63]. The development of the three Dietary Guidelines for Americans (DGA) patterns were informed by food pattern modelling and evidence on associations between dietary patterns and health outcomes[64].

The Planetary Health Diet (PHD), a global reference diet developed by the EAT–*Lancet* Commission on Sustainable Food Systems to meet nutritional needs within environmental limits, was also included[1]. The PHD pattern provides intake values for a 2,500 kcal d^{-1} pattern; therefore a 2,000 kcal d^{-1} pattern was derived by decreasing all recommended intake values by 20%.

Whereas all four of these selected dietary patterns have received some criticisms throughout the years[25,65], they have all been associated with decreased food-related chronic disease risk[66,67] and thus were chosen to be included in this study. Further information on the development and potential limitations of the PHD and other recommended patterns included in the analysis is provided in Supplementary Methods.

The intake values for the CURRENT and recommended DGA patterns were converted to grams using the conversion factors published in Blackstone and Conrad[68]. For the PHD pattern, intake recommendations for whole grains and legumes were originally provided as dry weight amounts. These values were converted to as-consumed amounts using conversion factors (2.13 for grains and 2.86 for legumes) obtained from Blackstone and Conrad[68]. The final intake values (grams per 2,000 kcal) for the 18 food subgroups across the five patterns are shown in Table 1.

Food subgroups. The food groups and subgroups from the DGA patterns were modified to reconcile differences with the CURRENT and/or PHD patterns.

First, the DGA patterns provide one recommended value for each of the following categories: (1) meats, poultry and eggs, (2) nuts, seeds and soy products and (3) whole fruit and 100% fruit juice, whereas the other patterns provide separate values for each of these food items. Therefore, the DGA recommended values were disaggregated into the more granular food items to enable comparison across all patterns. We used the NHANES 2015–2018 data to calculate the intake distribution of these individual food items and then applied that proportion to the aggregated values to obtain individual recommended values.

Second, in all three DGA patterns, legumes (that is, beans, peas, lentils) are classified as a vegetable subgroup, whereas the VEG pattern has an additional legume recommended value as a protein subgroup as well. To reconcile this, we created an overall legumes food subgroup that combined the vegetable and protein legumes values for the DGA patterns.

Additionally, the three DGA patterns provide a calorie limit for 'Other' uses, such as added sugars, saturated fats and alcohol. For this analysis, we assume these 'Other' calories are allocated to added sugars and saturated fats equally. For example, in the 2,000-kcal HUS pattern, the 'Other' calories are capped at 240 kcal, so we attribute 120 kcal (equivalent to 30 g) to added sugars and 120 kcal (equivalent to 13.33 g) to saturated fats in our calculations.

Lastly, we constructed a food group called 'Added Fats and Sugars (AFS)' that combines the recommended values for all added fats, including unsaturated and saturated, and added sugars across all patterns to

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enable a consistent comparison when evaluating the forced labour risk.

The final list of food subgroups and their definitions are in Supplementary Methods.

Food waste and inedible portions. The values presented for the current and recommended dietary patterns in Table 1 only refer to the amounts of food that are consumed and do not include the inedible and wasted portions associated with consumed food. However, the forced labour risk scores correspond to both consumed and inedible portions of food; therefore, we needed to adjust the consumption values for all five patterns to additionally incorporate inedible amounts of food. Moreover, we wanted to additionally calculate the risk for food that is wasted at the consumer level, so we also needed to adjust the consumption values to incorporate wasted amounts of food as well.

To do this, we utilized the same methodology used in Conrad et al.[69] and the corresponding food waste and inedible coefficients calculated from previous studies[70,71]. In summary, we first broke down each NHANES dish into its individual ingredients using the Food Commodity Intake Database[72], which contains data on the weight of nearly 500 ingredients in each NHANES dish. We then used the Conrad et al. dataset to assign wasted and inedible coefficients to each ingredient, which allowed us to calculate the total amounts of wasted and inedible food for each dish. Next, we used our data crosswalk from the Food Commodity Intake Database (FCID; that is, ingredient) codes to 18 distinct food subgroups to determine the total amounts of consumed, inedible and wasted food, by food subgroup, for each NHANES participant. Finally, we calculated the average amounts of consumed, inedible and wasted food, by food subgroup, accounting for the complex survey design of NHANES.

The following equations were used to calculate the food subgroup-level wasted and inedible coefficients:

$$\text{Wasted food coefficient} = \text{Wasted food amount}/\text{Consumed food amount}$$

$$\text{Inedible food coefficient} = \text{Inedible food amount}/\text{Consumed food amount}$$

These coefficients were then applied to the consumed food amounts in each dietary pattern to estimate the total amounts of consumed, wasted and inedible food (Supplementary Table 5).

Data processing

Data mappings. The following data mappings (that is, crosswalks) were manually constructed by the research team to connect the datasets described above:

Mapping from FCID commodity codes to food subgroups. The FCID commodity codes, which represent food commodities rather than foods as consumed (for example, wheat flour and whole egg versus noodles), were assigned to 18 food subgroups based on the What We Eat in America (WWEIA) Food Categories 2017–2018[73]. After reviewing these classifications, the research team decided to reclassify 3.9% (16/410) of the FCID codes (not including baby food and water) to food subgroups that we deemed were a better fit. The final mapping is provided in Supplementary Table 6.

Mapping from Food and Nutrient Database for Dietary Studies food codes to food subgroups. Similarly, the Food and Nutrient Database for Dietary Studies (FNDDS) food codes, which uniquely identify each food or beverage item in FNDDS, were assigned to 18 food subgroups based on the food classification scheme provided by the first two to four digits of the FNDDS food code[74] and the four United States Department of Agriculture (USDA) food categories[75]. The mapping is provided in Supplementary Tables 7 and 8.

Mapping from FCID codes to forced labour risk scores. The risk scores for 147 land-based food products (Supplementary Tables 9 and 10) were manually mapped to the relevant 401 FCID ingredients in the NHANES data by two members of the research team independently, and any disagreements in mappings were resolved by a third member. This protocol is further described in Supplementary Table 11.

Additionally, weight conversion factors were used to adjust from the weight basis as defined by the Food and Agriculture Organization of the United Nations (FAO) and the weight basis utilized by FCID. Weight conversion factors were retrieved from a number of sources, including (1) USDA's Food Intakes Converted to Retail Commodities Database, 2007–2008[76], (2) FAO's Technical Conversion Factors[77], (3) USDA's Conversion Factors and Weights and Measures for Agricultural Commodities and Their Products[78] and (4) USDA's National Nutrient Database for Standard Reference, Legacy Release[79]. Conversion factors were selected following a detailed protocol, provided in Supplementary Table 12.

Mapping from FNDDS codes to forced labour risk scores. For seafood, an adapted approach was taken. There were only six seafood-related FCID commodities available for mapping: freshwater finfish, freshwater finfish (farm raised), saltwater finfish (tuna), saltwater finfish (other), shellfish (crustacean) and shellfish (mollusc); our new dataset, however, included forced labour risk scores for 48 seafood products. Rather than using a weighted average approach to represent each of the six FCID seafood commodities, following the same mapping process described above, two team members matched the 22 condensed seafood risk scores (Supplementary Table 1) to seafood dishes in NHANES (at the FNDDS-level) based on the dish descriptions (which typically described the type of seafood consumed, for example, salmon, catfish, oysters and so on). If the FNDDS dish description did not specify the seafood product (for example, fish sandwich, seafood dip), then we created a weighted average risk score for these unspecific seafood commodities based on the global production volumes of all seafood products[80]. The detailed protocol for this mapping process is available in Supplementary Table 13.

In our analysis, we also utilized a crosswalk from FCID codes to FNDDS codes published by Conrad et al.[39,72].

Impact factors. First, the forced labour risk scores for each food commodity in the US food supply were obtained from prior work, which developed a method to assess the risk of forced labour in food value chains[22]. These scores, originally in the unit of medium risk hours-equivalent (mrh-eq) per ton of food produced, were divided by 1,000,000 to convert to mrh-eq per gram of food produced. We also created average risk scores for tropical fruit, seeds, grains, beans, flours and poultry by averaging the risk scores of their related food commodities. These average scores were applied to FCID commodities that did not have an available match in the forced labour risk dataset.

Then, we multiplied the risk scores by the corresponding consumed amount in the NHANES dataset to get the total forced labour risk per food item, per day, per NHANES participant. If participants had two days of diet recall, then Day 1's and Day 2's amounts of forced labour risk and consumed and inedible amounts were used to get a daily average. If participants had 1 day of diet recall, then Day 1's values were used as the daily average.

Lastly, accounting for NHANES sampling weights and survey design parameters, we calculated (1) average daily amount of forced labour risk, by food subgroup, and (2) average daily consumed and inedible amount, by food subgroup. The final forced labour risk impact factors for each food subgroup were calculated:

$$\begin{aligned}&\text{Forced labour risk per 1 gram of food } (i)\\&= \text{Average daily amount of forced labour risk } (i)\,/\\&\ \text{Average daily consumed and inedible amounts } (i)\end{aligned}$$

for food subgroup i (Table 1).

Statistical analysis

The total forced labour risk for each pattern was calculated by multiplying the food-subgroup-specific risk impact factors by the corresponding intake amounts and summing these values across all food subgroups. For each dietary pattern, the percent contribution of each food subgroup was calculated as the ratio of its forced labour risk to the total forced labour risk for that dietary pattern.

We also calculated each protein food subgroup's percentage contribution to (1) total protein intake and (2) total forced labour risk of the overall dietary pattern. This allowed quantifying the relative impact of different protein sources on the forced labour risk of each dietary pattern.

Sensitivity analyses

Because our model is driven by several assumptions (for example, allocation of commodities to aggregated NHANES food groups, forced labour risk based on a weighted average of US food supply), we selected a sensitivity analysis to explore uncertainties among scenarios. The results presented in our sensitivity analyses quantify how variations in these assumptions affect our results, which is interpreted as the robustness of our model under different premises.

Two different sensitivity analyses were conducted to assess the robustness of the main results. The first focused on the risk scores for each of the 18 food subgroups, replacing the baseline scores with the minimum and maximum FCID-level scores in separate scenarios to understand how that would impact the overall diet rankings in terms of total risk. For example, the food commodities with the lowest and highest risk scores contributing to the whole fruit subgroup's weighted score (0.016 mrh-eq $(100\ g)^{-1}$) were pomelo (0.004 mrh-eq $(100\ g)^{-1}$) and avocado (0.156 mrh-eq), respectively. In the minimum scenario, the pomelo score was used in replacement of the whole fruit subgroup's score. Likewise, in the maximum scenario, the avocado was used (a total of 36 scenarios were conducted).

The second sensitivity analysis evaluated the impact of including or excluding the feed-related risk scores for animal-based food subgroups, comparing the baseline scenario that included feed scores to a scenario that did not.

Reporting summary

Further information on research design is available in the Nature Portfolio Reporting Summary linked to this article.

Data availability

The detailed results and background data files are available for download via Zenodo at https://doi.org/10.5281/zenodo.16815633 (ref. 81). Source data are provided with this paper.

Code availability

Data processing and analysis were performed using R (v.4.4.0), Microsoft Excel (v.16.83), TableauPrep (v.2024.1) and TableauDesktop (v.2023.2.0). R scripts are available for download via Zenodo at https://doi.org/10.5281/zenodo.16815633 (ref. 81). The associated GitHub repository is located at https://github.com/brookembell/forced-labor.

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Author contributions

Author contributions are listed alphabetically within each category. J.L.D.S. and N.T.B. conceptualized the study. B.M.B., B.J., E.R.-H., J.L.D.S. and N.T.B. designed the methodology. C.B.N. and Z.C. provided expert input on the methodology. B.M.B. and E.R.-H. developed the code. A.S.M., B.M.B., B.J., E.R.-H., J.L.D.S. and K.B. collected and analysed the data. B.M.B., B.J., E.R.-H., J.L.D.S. and N.T.B. wrote the original draft. All authors edited, reviewed and approved the final version of the paper. J.L.D.S., B.J. and N.T.B. supervised and administered the project. Both B.M.B. and E.R.-H. contributed equally to the work as first authors and have the right to list their name first on their CV. Both B.J. and N.T.B. contributed equally as senior authors and have the right to list their name last on their CV.

Competing interests

C.B.N. declares that she was a Research Scientist in Social Responsibility with Amazon, Inc. for part of the time this research was in progress and began a role with Target as Senior Social Sustainability Manager when this project was close to completion. C.B.N. is also co-owner of NewEarth B and the Social Hotspots Database project. Data from the Social Hotspots Database were provided free of charge for academic use in this research. The other authors declare no competing interests.

Additional information

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Extended Data Fig. 1 | Distribution of FCID-commodity intake (g), by food subgroup. All data are presented as percentages. The bars in the top row show the US adult intake (grams) distribution of vegetable and fruit commodities. The bars in the middle row show the intake distribution of animal-based foods including meats, seafood, eggs, saturated fat and dairy. The bars in the bottom row show the intake distribution of plant-based foods including nuts and seeds, legumes, grains, unsaturated fats and added sugars. Contributions less than 2.5% of the total in each bar are not labelled.

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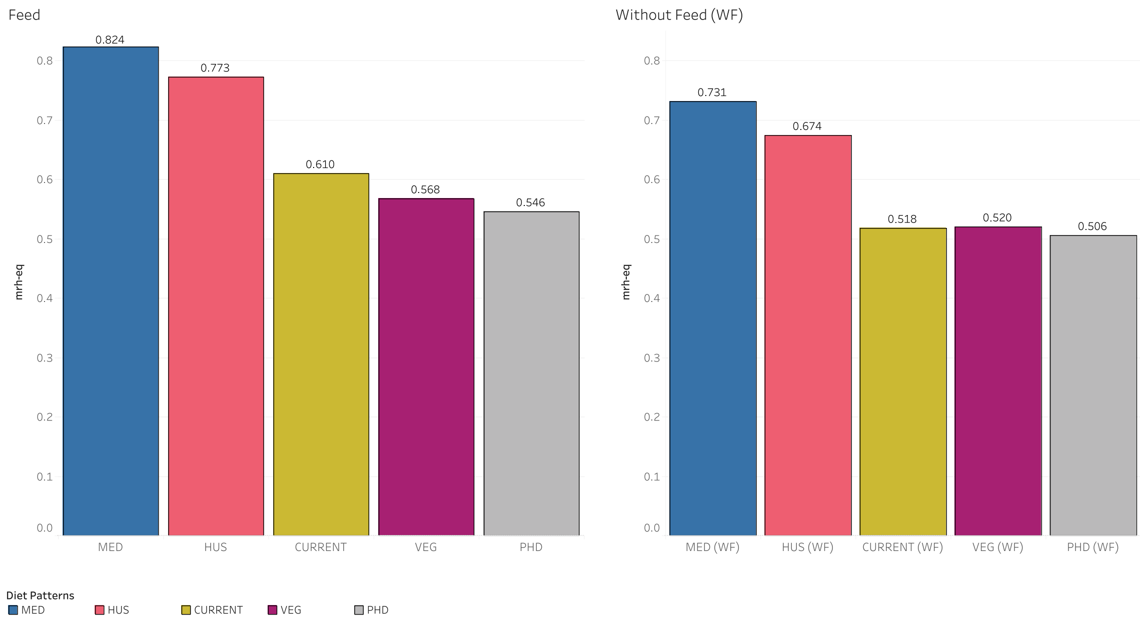
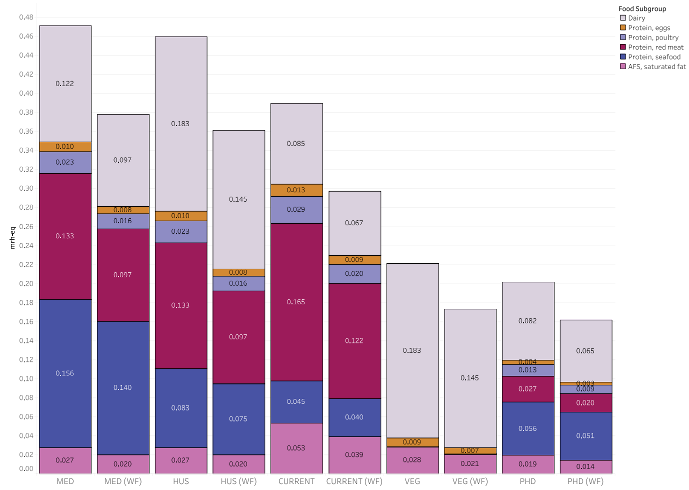


Extended Data Fig. 2 | Overall risk for each pattern, feed vs. without feed. Each bar represents the total amount of forced labour risk, as measured in the units mrh-eq, for each dietary pattern. The left panel `Feed` shows total risk including the risk embedded in animal feed, whereas the right panel `Without Feed (WF)` shows total risk excluding the risk embedded in animal feed. WF, without feed.

https://doi.org/10.1038/s43016-025-01242-8



Extended Data Fig. 3 | Risk by food subgroup, feed vs. without feed. Each bar represents the total amount of forced labour risk, as measured in the units mrh-eq, by food subgroup, for each dietary pattern. The different color segments correspond to the risk amounts attributable to each animal-based food subgroup. WF, without feed.

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Research sample	Current dietary intake was estimated using nationally representative data from two recent waves of the National Health and Nutrition Examination Survey (NHANES) (2015-2016 and 2017-2018). We included participants who were aged 20 years or older and provided at least one reliable dietary recall (n=9,759).
Sampling strategy	Not applicable. Risk estimates observed in figures are provided either on a weighted basis, where the weight is proportional to the supply coming from different countries of origin, or unweighted, where the risk refers to a product from one country.
Data collection	No primary data collection with participants to report. Collection of data from investigative journalism and other publicly available sources was completed with the disclosed softwares. No experimental condition or study hypothesis to report (and thus no blinding).
Timing	Dietary intake data were collected from 2015-2016 and 2017-2018.
Data exclusions	We excluded NHANES participants if they did not provide at least one reliable dietary recall (n=2,440) or if they were were under the age of 20 (n=6,049). Exclusion criteria were pre-established.
Non-participation	No human participants were involved in the study.
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