Title: Risk of forced labor embedded in the US fruit and vegetable supply

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Abstract

Sustainable food consumption studies have largely focused on promoting human health within ecological limits. Less attention has been paid to social sustainability, in part because of limited data and models. Globally, agriculture has one of the highest incidences of forced labor, with exploitative conditions enabled by low margins, domestic labor scarcity, inadequate legal protections for workers, and high labor requirements. This research assesses the forced labor risk embedded in the US retail supply of fruits and vegetables. We demonstrate there is risk of forced labor in a broad set of fruit and vegetable commodities, with a small number of commodities accounting for a significant fraction of total forced labor risk at the retail supply level. These findings signal potential trade-offs and synergies across dimensions of food systems sustainability and the need for novel research approaches to develop evidence-based forced labor risk mitigation strategies.

Main

An estimated 1.8 million workers globally are subjected to forced labor in agriculture and fishing.[1] This means that in order to meet the Sustainable Development Goal (SDG) 8.7 by 2030, exploitive working conditions for over 600 workers need to be eradicated each day.[2] Defined by the International Labour Organization, “forced labor refers to situations in which persons are coerced to work through the use of violence or intimidation, or by more subtle means such as accumulated debt, retention of identity papers, or threats of denunciation to immigration authorities.”[3] Within agriculture, the conditions for forced labor to occur are shaped by remote and isolated work environments, low margins, seasonal work, inadequate legal protections, shifts toward piece rate pay systems, sustained downward pressure on prices, domestic labor scarcity and reliance on migrant labor, and high labor requirements, particularly for harvesting delicate products.[4,5]

Although the persistence of forced labor in food production is well-documented globally[5–7], and its elimination is of clear policy importance, the systemic precarity of many work arrangements, illegality, and supply chain opacity create data and management challenges.[8] Thus, there remains a need for supply chain approaches that transcend disciplinary silos to develop and improve metrics for detection.[9] Although social life cycle assessment (S-LCA) has emerged to partially fill this gap, its practice is still at a developmental stage.[10] Critical challenges include defining consistent and valid social indicators, the development of datasets beyond the country and sector level and across the life cycle, and ensuring methodological rigor.[10,11] Empirical S-LCA research on the social performance of foods has largely been case study-based, with the agricultural stage commonly identified as a driver of risks or impacts.[12–15]

Besides inhibiting the achievement of the SDGs, the lack of data on forced labor and other labor-related social risks means that interventions to improve environmental or health outcomes of food systems may result in unintended consequences. For example, national and international authorities have promoted foods with high labor requirements (e.g., some produce; wild-caught fish) to enhance nutrition and reduce burdens on ecosystems. These foods may have high labor-related social risks; promoting their consumption without addressing the upstream labor conditions may unintentionally exacerbate existing inequities.

Sustainably meeting future food needs will require systems transformation, which must be supported by an evidence-based approach that captures its complexities. The objective of this research is to assess the risk of forced labor associated with fruits and vegetables consumed in the US by compiling distinct datasets and developing a new forced labor risk scoring method.

We assess forced labor risk 1) per serving, to compare risk across numerous fresh and processed fruits and vegetables; and 2) at the level of the US retail fruit and vegetable supplies, including retail waste and loss, to identify risk hotspots.

To compute forced labor risk, we first compiled origin data for the US fruit and vegetable supply. Second, we qualitatively coded the forced labor risk in agricultural production for each country-commodity combination using a three-tiered approach, with the most granular data available used in the final assessment **(Table 1)**. Consistent with the Social Hotspots Database (SHDB)[16], we applied conversion factors to translate qualitative risk levels into quantitative scores in the unit medium risk hours equivalent (mrh-eq). Risk of forced labor was calculated as a function of characterized risk and worker hours (calculated from country-sector specific labor intensity per dollar and commodity prices).

Results

The final dataset included 93 fruit and vegetable commodities corresponding to 307 commodity-country combinations. More than half of the combinations (57%) in the forced labor risk analysis relied on data that was specific to the commodity and country of origin (Step 1; see **Table 1**). 42.7% and 0.3% of combinations were supported by data at the sector-country level (Step 2) or country-level (Step 3), respectively. The results of the qualitative coding of forced labor risk show that most commodity-country combinations were coded as High Risk (85%). Of the commodity-country combinations coded as High Risk, 54% were due to hand harvest of the commodity and sector-level risk in the country (part of Step 1 coding; see Table 1). Seven percent of combinations were coded as Very High Risk, and the remaining eight percent of combinations were coded as Medium (4.5%) or Low (3.5%) Risk.

Per-serving forced labor risk associated with fruits and vegetables

Forced labor risk is compared separately for fruits and vegetables, with Jenks natural breaks optimization used to identify commodities with more risk per serving in the dataset. Risk scores for commodities are weighted according to the share of supply from each country of origin (by mass).

Forced labor risk scores for fruit ranged from 1.3 to 0.016 mrh-eq, a difference of about two orders of magnitude **(Figure 1)**. Fruits categorized as having more forced labor risk included several types of berries (processed blackberries, fresh and processed raspberries), citrus (fresh tangerines, lemons, and limes), pineapples, fresh mangoes, avocados, and papayas. Processed blackberries were sourced from two countries (Chile and Mexico), and were qualitatively assessed as High Risk based on Step 2 data. Blackberries had the highest labor intensity (sector worker hours per serving) among all fruits, due to their countries of origin. Fresh and processed raspberries were sourced from two countries (Mexico and US), with all combinations assessed as High Risk based on Step 1 (fresh) or Step 2 (processed) data. Fresh and processed raspberries had the second and third highest labor intensity per serving among fruits.

All sources of fresh tangerines (Italy, Mexico, Peru), lemons, and limes (Argentina, Mexico, US) were assessed as High Risk using Step 1 data. These commodities had the fourth and fifth (lemons and limes tied) highest labor intensities per serving in the dataset. While fresh and processed pineapples are not as labor intensive, they were sourced from five countries, with three sources assessed as Very High Risk (Costa Rica, Thailand, US) according to Step 1 data. Finally, fresh mangoes, avocados, and papayas had all sources assessed at high risk according to Step 1 (mangoes and avocados) or 2 (papayas) and have relatively high labor intensities per serving.

Vegetables had a wider range of forced labor risk, from 1.7 to 0.0099 mrh-eq **(Figure 2).** Commodities categorized as having more risk per serving were fresh and processed asparagus, fresh okra, and processed chile peppers; these had the top four labor intensities of all vegetables. Asparagus was sourced from three countries (Mexico, Peru, US), all of which were assessed as High Risk based on Step 1 data. Okra was sourced from four countries (Mexico, El Salvador, US, Honduras), with all sources assessed as High Risk based on Step 1 data except Honduras, which was Low Risk (Step 2). Processed chile peppers were sourced from three countries, two of which were assessed as High Risk (Canada and US) and one as Very High Risk (Mexico) based on Step 1 data.

Within vegetables, a small number of commodity-country combinations stood out as having much higher maximum forced labor risk than their weighted averages **(Figure 2).** For example, fresh tomatoes and artichokes were sourced from the US and Mexico, with the US providing most of the supplies for each (88% and 98%, respectively). In both cases, the maximum risk source was Mexico, based on Step 1 data. The combination of a Very High (tomatoes) or High (artichokes) Risk code and relatively high sector labor intensity was responsible for the notably high maximum risk. Similarly, for fresh sweet corn, most of the supply was from the US (98%), which was assessed as Medium Risk using Step 1 data. The maximum risk source was Thailand, which was assessed as High Risk using Step 2 data and has a relatively high sector labor intensity.

Fruit and Vegetable Retail Supply Risk

Assessing forced labor risk at the level of the total US retail supplies of fruits and vegetables provided a different picture. Retail supply data included retail-level food waste and loss. Of the forced labor risk embedded in the US retail fruit and vegetable supplies, 13% and 12% was wasted, respectively. Comparing per-serving results with total supply results, some, but not all, commodities that were categorized as having more per-serving risk also contributed a large portion of the total forced labor risk embedded in the retail supply **(Figure 3)**. For example, five fruit commodities accounted for 39% of the total risk in the US retail fruit supply: fresh avocados, bananas, tangerines, and fresh and processed pineapples. All of these commodities except bananas were categorized as having more risk, but because bananas were the number one fruit (by mass) supplied at the retail level, they contributed a high fraction of retail supply risk.

For vegetables, five commodities accounted for 55% of the total risk in the US retail vegetable supply: fresh and processed tomatoes, fresh green peppers, processed chile peppers, and fresh asparagus. Tomatoes alone accounted for 25% of the retail vegetable supply risk. Fresh and processing tomatoes were the number three and five commodities, respectively, in the retail supply on a mass basis, and have relatively high risk compared to other vegetables.

Discussion

We find a risk of forced labor in the agricultural production of a broader set of fruits and vegetables consumed in the US than has been previously represented. A staggering 85% of commodity-country combinations were coded to be at high risk of forced labor, with another 7% at very high risk. Recent media corroborates our findings for commodities identified as having more risk, including pineapple,[17–19] avocado,[20,21] and chile peppers.[22,23] While our findings are congruent with other catalogues of risky commodities,[6,24,25] our approach enables moving beyond the standard binary categorizations of risk. These results point to the need for policymakers, companies, farmers, workers, and communities to come together to address the systemic issues (examples in **Table 2**) at the source of the vulnerabilities related to fruit and vegetable production. For their part, consumers can demand further transparency regarding at risk commodities, seek out and ask grocers to carry produce certified under proven certifications such as the Fair Food Program.[26,27]

Our method enables supply chain stakeholders to not only have a commodity-by-commodity, quantitative view of forced labor risk, it importantly allows for aggregation and analysis at the food supply or product portfolio levels. While many commodities are at higher risk, a small number of commodities account for significant fractions of the risk embedded in the US retail fruit and vegetable supplies. This is important for retailers as they can target their response to address the risk associated with particular fruits and vegetables instead of applying blanket verification, largely found to be ineffective.[28] Additionally, identifying the wasted fractions of forced labor risk at retail makes visible a social sustainability aspect of food waste and loss, similar to prior research that has documented its embedded environmental[29–31], economic[32], and nutritional[30,33] costs.

Our results are also informative to companies and policymakers developing and implementing procurement requirements. Our data and methods can inform risk-based due diligence according to the OECD-FAO Guidance for Responsible Agricultural Supply Chains.[34] Due diligence requires that organizations identify, analyze, mitigate, prevent, and ultimately account for potential and actual adverse impacts of their operations.[34] Due diligence, transparency, and public commitments regarding forced labor are critical to achieving SDG 8.7. A recent analysis of 350 of the world's most significant food and agriculture companies found that 40% did not publicly disclose a commitment to eliminate forced and child labor from their supply chains.[35] For companies procuring fruit and vegetable commodities within the US, our results point to the urgent need to transparently address potential embedded forced labor risks in their supply chains.

Analyzing risk at this systemic level is not only useful for prioritizing risk mitigation efforts but also for preventing shifting of risks. For instance, when media attention or policy responses are focused on one commodity in a country, vulnerable workers and their exploiters may move to another geographic region or shift to another commodity, displacing the risk, not removing it. For foreign produced commodities, the use of import bans (either short- or long-term) may result in sourcing from other countries with potentially unknown or underappreciated labor risks, to maintain supply without safeguards.

Country-commodity combinations that are major contributors to US supply risk also represent a spectrum of value to the source countries, suggesting a need for nuanced policy responses. For example, tomatoes were the largest contributor to vegetable supply risk in this analysis, with Mexico and Canada as the primary importing countries. For Canada, tomatoes represent less than 1% of agricultural production value.[36] Migrant workers hired through the Temporary Foreign Worker Program are vulnerable to forced labor due to loopholes similar to the United States' H-2A temporary agricultural workers' visa.[37] Whereas for Mexico, tomatoes are a major crop, representing 3% of the country's agricultural production value[36], and workers are mostly local. For Mexico, a total ban on imports would likely worsen the very socio-economic vulnerabilities that drive the risk of forced labor domestically and the risk associated with migrating to other countries' agricultural sectors.[9] Our analysis represents a first step toward adapting and using supply-chain approaches for the detection of forced labor, and with more comprehensive data, its expansion could allow for the targeted investigations necessary for auditing and government agencies to develop more specific policies.

Notably, we identified forced labor risk in a substantial segment of the domestically produced US fruit and vegetable supply. Most research on modern slavery in supply chains focuses on global value chains, particularly those originating in low- and middle- income countries.[38] This is at the exclusion of scrutinizing domestic supply chains in high-income countries[38] and despite a lack of cogent evidence that high-income importing countries' labor standards create a market incentive for improved labor conditions in low- and middle-income export countries.[39] Using the lens of the total fruit and vegetable supplies in this analysis connects domestic and global supply chains – an advancement for the modern slavery field.

It is unlikely that the forced labor risk we identified in US production is merely a product of more stringent monitoring and enforcement stemming from better governance. Forced labor persists in the agricultural sectors of many high-income countries[1] because: 1) the same dimensions of risk are salient across low, middle, and high-income countries regardless of governance (e.g., precarious work, dependency on migrant workers); 2) farm profitability is volatile, and the sector is spatially fixed;[38] 3) producers may use agents charging recruitment fees that represent a substantial share, equate or even surpass workers' wages;[6] and 4) improved enforcement does not equate to improved detection due to the prioritization of immigration violations over labor violations when workers report grievances.[40,41]

Limitations and future research

Though this novel analysis represented a step-change in improving the scope and scalability of quantitative forced labor risk estimates, a dearth of commodity-level data resulted in several limitations. The Very High Risk classification was only an option in Step 1, where either 1) there were documented occurrences of forced labor in the commodity-country combination according to Verité's *Strengthening Protections Against Trafficking in Persons in Federal and Corporate Supply Chains* report[6] or 2) the commodity-country combination was included on the US Department of Labor's (DoL) *List of Goods Produced by Child Labor or Forced Labor.*[24] DoL does not assess commodities, but rather receives and analyzes evidence to determine if a commodity-country combination meets the threshold for listing. On the other hand, Verité compiles comprehensive information on each commodity it assesses, but its report only details information on a limited number of commodities. This gap of known cases of forced labor in commodity-country combinations is likely large. There is no known repository of forced labor cases in agriculture globally or nationally, except Brazil's 'dirty list' (lista suja).[42] Furthermore, data produced by organizations such as the International Labour Organization often aggregate agriculture with fishing and forestry.[1] New sources of more comprehensive data would allow for a more complete analysis.

Labor intensity data strongly influenced modeled risk, but was only available at the country-sector level and per dollar of sector output. As such, this variable could not represent real differences in the intensity of labor required across the production of fruit and vegetable commodities within a given country. Using a measure of labor intensity based on dollars of output resulted in higher-priced commodities being associated with higher risk and lower-priced commodities with lower risk, relative to other items in the dataset. However, price is not always a reliable predictor of forced labor in agriculture. Due to this limitation in our labor intensity data, we accounted for one critical aspect of labor intensity and forced labor risk, hand versus mechanical harvest[6], in our qualitative risk coding process. Hand harvest was coded as a commodity-region specific determinant of forced labor risk, when data were available (see Methods section).

Commodities with less risk in the results are not necessarily void of forced labor, for multiple reasons. First, the absence of forced labor occurrences in our data sources may reflect inconsistent or underdeveloped country-level reporting structures. For example, okra from Honduras was assessed as Low Risk according to our coding schema and sources, but this may well be due to inadequate reporting in the country. Additionally, this analysis focused exclusively on risk in agriculture, but there are also other supply chain nodes with documented cases of forced labor, particularly food processing. For example, cases of forced labor were reported in a potato packing facility in Texas during this analysis.[43] Potatoes were the lowest risk vegetable in the analysis, which reflects a limitation of assessing risk solely at the agriculture stage. This also attests to the fact that low forced labor risk commodities are not risk-free and that our conservative methodological approach likely produced an underestimation.

Although the scope of this initial analysis was limited to agriculture, our method to characterize forced labor risk aligns with the S-LCA approach and associated databases (i.e., Social Hotspots Database and Product Social Impact Life Cycle Assessment Database). This alignment facilitates future risk assessments that span full product supply chains, by combining and expanding our higher resolution data (i.e., commodity-country specific) with more generic background data for other supply chain stages from S-LCA databases. This represents an advance in S-LCA practice, which typically relies on generic (i.e., sector and/or country specific) data for scoping analyses of risk and company-specific primary data within supply chains for higher resolution analyses.[10] The latter is generally inaccessible to stakeholders outside of those supply chains (e.g., the public), and may be inaccessible or difficult to attain even for companies' own supply chains due to lack of traceability for far upstream suppliers.

Despite these limitations, alignment with the S-LCA approach enables quantitative risk assessments that can be conducted within and across food supply chains, when sufficient data are available. To date, the lack of scope and scalability of risk estimates has prevented the inclusion of forced labor data into analyses of sustainable diets and food systems. The forced labor risk assessment methods used in this analysis provide a viable starting point for measuring a critical indicator for the social sustainability of food systems.

Conclusion

Forced labor in agriculture is a threat to the sustainability of food systems. However, the scarcity of data noted limits holistic analysis and action. Future research should prioritize data and model development to enable analyses of forced labor and other labor-related social risks (e.g., wages, child labor) across the life cycles of a wide range of foods. These efforts can help ensure that the rights and dignity of "the hands that feed us"[44] are centered in the transformation of food systems.

Methods

Data for this forced labor risk assessment were managed and analyzed in Microsoft Excel and R softwares. The overall calculation for forced labor risk per serving of fruit or vegetable is described by the equations below

$$CF_{i,k} \times WrkHrs_i \times Price_k = FL_{i,k} \tag{1.1}$$

$$\sum_{i=1}^{n} FL_{i,k} \times Prop_{i,k} = MeanFL_k \tag{1.2}$$

where each fruit and vegetable commodity is denoted by *k* and each country of origin is denoted by *i*; CF is the risk characterization factor assigned to commodity *k* from country *i*; WrkHrs is the labor intensity for the vegetable and fruit sector in country *i* (hours per dollar, in producer prices); Price is the price of commodity *k* (dollars per serving, in producer prices); FL is the forced labor risk per serving for each commodity *k* from origin country *i*; Prop is the proportion of supply of commodity k accounted for by country *i*; and MeanFL is the weighted average forced labor risk per serving for each commodity *k*.

Fruit and vegetable supply data

We used import quantities and origins from FAO's Food Balance Sheets,[45] averaged over the years 2011-2013, and converted quantities to their primary equivalent in metric tons using commodity- and country-specific extraction rates from Kim et al. (2019).[46] Using these import quantities, we calculated each import country's share of total US imports for each item, and excluded those countries responsible for <5% of total imports. This cutoff rule was applied to simplify data collection and because the risk level of a very small fraction of a commodity's import origins – and an even smaller fraction of the total supply of a commodity – did not meaningfully affect the risk level of the total commodity in a partial sensitivity analysis (see Supplementary Materials).

Consistent with FAO's method for preparing and publishing the FBS,[47] we calculated total US domestic supply of a commodity by subtracting exports from the sum of US production, imports, and stock changes, averaged over 2011-2013.[45] We then calculated the proportion of each commodity in the US food supply that was produced domestically by subtracting total import share (total imports divided by the domestic supply) from 1.

Some FBS items were too broad to enable meaningful analysis of labor risk (e.g. Fruits, Other). We disaggregated these items into their components based on FAO's Definitions and Standards[45] and extracted import data from FAO's detailed trade matrix.[48] We then used the per capita availability of each disaggregated commodity from USDA's Food Availability Data System,[49] and multiplied by the US population to calculate US domestic supply. We harmonized these USDA commodities with the disaggregated components of the FBS items, excluding those FBS components without corresponding USDA data.

After disaggregating FBS items where necessary, our full dataset included 57 fruit and vegetable commodities (Table S2). We mapped these commodities to items in the US Department of Agriculture's Loss-Adjusted Food Availability (LAFA) data series for the year

2018[49], aggregating items with multiple processed forms into one processed product (Table S3). We excluded six items from the LAFA dataset that were either too aggregated to assess risk (e.g. frozen fruit) or had a zero value for retail availability in 2018 (e.g., dried pears). The final aggregated LAFA fresh and processed commodities (n=93) are the unit of analysis, (k) in the equations above.

Labor intensity and prices

We used labor intensity data (worker hours per $1 of country-specific sector output) from the Social Hotspots Database (SHDB).[16] The sectors in the SHDB come from the Global Trade Analysis Project (GTAP) database. SHDB data for average wage rates were collected for the greater part from the UNIDO and ILOSTAT databases (about 85%).[50] To complete the dataset, data from national statistics, employment sites and about minimum wages were used.[50] Data available in local currency were converted to USD for the reference year.[50] Data were mapped from the available classification/ granularity to the relevant GTAP sector classification.[50] Only one sector was used for this analysis: vegetables, fruits and nuts. Labor intensity data corresponds to this broad sector at the country level (e.g., vegetables, fruits, and nuts production in the US). The SHDB labor intensity data use producer prices.

We used average US retail prices per cup equivalent (serving) and per unit sold (mass or volume) from the U.S. Department of Agriculture's Fruit and Vegetable Prices dataset.[51] Prices per serving in this dataset are adjusted for a preparation yield factor, accounting for inedible portion and cooking loss/gain as appropriate. Prices were often provided for multiple processed forms of fruits and vegetable commodities (e.g., apple juice, apple sauce, frozen apples). In these cases, prices were aggregated to a weighted average processed commodity price, as a function of all processed forms' contributions to the total processed commodity mass according to LAFA. Retail prices were deflated to producer prices using a multiplier derived from data on commodity margins from the US Bureau of Economic Analysis[52] (See Supplementary Materials).

Qualitative coding of forced labor risk levels

Due to a paucity of data, forced labor risk was constructed through a multi-step process wherein risk was qualitatively coded using data on known occurrences and government response **(Table 1).** Known occurrence data required the use of multiple sources to cover all country-commodity combinations and was sorted by resolution in "steps". Step 1 was commodity-country specific risk using Verite's Strengthening Protections Against Trafficking in Persons in Federal and Corporate Supply Chains report,[6] the United States Department of Labor's (DoL) *List of Goods Produced by Child Labor or Forced Labor,*[24] and several sources focused on harvest methods (See Supplementary Materials). Step 2 was sector-country specific risk using the United States Department of State's (USDoS) Human Rights Report (HRR)[53] and the USDoS's *2019 Trafficking in Persons* (TIP) report.[54] Step 3 was country-specific risk generated from the Global Slavery Index (GSI).[55] Risk from the highest resolution step of data available was used in the final quantitative score. Government response data was extracted from the TIP report.[54]

Specifically, two researchers independently coded each data source using a codebook written a priori. An interrater reliability target was also set at .90 to ensure consistent application of codes. Coding disagreements between researchers were negotiated until consensus was achieved. When both known occurrences and government response data were available for a commodity-country combination, a weighted average risk level was calculated (85% known occurrences, 15% governance), following the Social Hotspots Database method for forced labor assessment[50] (See Supplementary Materials). When either known occurrences or government response data were unavailable for a commodity-country combination, the risk level was based on the highest resolution data available.

For Step 1 known occurrences data, risk in the Verité report was coded as very high risk, medium risk, or not applicable. The DoL report was coded as very high (due to the stringent evidence requirements for a commodity to make the list)[24] or not applicable since the report uses a binary system where commodities are either listed or not. If a commodity was not included in either report, the risk was not assessed as exclusion did not equate to no risk.

To supplement Step 1 known occurrences data, an additional sub-step was conducted to assess commodity-specific risk associated with hand harvesting. Hand harvesting is more likely to engender forced labor than mechanical harvesting.[6] Reports from USDA[56] and broader web-based searches were used to determine if a crop was hand or mechanically harvested in a specified country. If it was reported that harvest aides were used, the crop was conservatively coded as a mechanized harvest since harvest aides are intended to reduce labor inputs. After the initial search, numerous country-commodity combinations remained data insufficient. Some data gaps were able to be filled through expert elicitation (Table S1). When data were unavailable, risk was not assessed, as lack of data did not equate to no risk. Once commodity-country combinations were coded as hand or mechanical harvest, we cross-referenced Step 2 data on known occurrences of forced labor in the country's agricultural sector (described below). If a commodity was hand harvested and evidence of forced labor risk existed in the country's agricultural sector, risk was coded as high.

Step 2 had a similar structure to step 1 but used the HRR[53] and TIP report.[54] In the HRR, sector specific data related to "Workers Rights, Prohibition of Forced or Compulsory Labor" were noted in Section 7b in the 2018 version of the report used. 50 unique countries were identified for the custom report built according to all countries present in our dataset; the U.S. was exempt as it is not included in the HRR. 'Agricultur*' and 'farm*' sectors were searched for within the report and coded as either ‘high’, ‘medium’, or ‘low’. The TIP report narratives were also searched for the same terms and coded with the same risk levels. When sector data was not available in either report’s country narrative their risk was denoted as ‘not applicable’ so that risk was not skewed by the lack of data. In step 3, the country-level risk was calculated by coding the 2016 GSI[29] to provide percentages of workers subjected to modern slavery and the risk levels of this occurring. The qualitative codes included: >0.70% = high, >0.30% = medium, >0.20% = low, and <0.19% = very low; these thresholds were adapted from the Social Hotspots Database[16] forced labor assessment method. Overall, we took a conservative approach to risk assessment and structured the codes to reflect uncertainty. For example, a “very high” risk code was only applied to commodity-country specific data, and a “very low” risk code was only applied to country-specific data.

Government response data from the TIP report was coded as very high, high, medium, or low risk, or not applicable, following the Social Hotspots Database approach. Codes corresponded to the country tier classifications provided by the TIP report (Tier 3, 2W, 2, 1) which refers to different levels of compliance with the TVPA.

Quantitative scoring of forced labor risk

Finally, we applied characterization factors to convert risk levels to medium risk hours equivalent (mrh eq) per serving. Used in the Social Hotspots Database, the unit medium risk hours equivalent enables straightforward, scalable comparisons across products and identification of risk hotspots within a supply chain. An analogue in environmental life cycle assessment is carbon dioxide equivalents (CO_2-eq), where the characterization factor for each emission corresponds to its global warming potential over a particular time frame (e.g., 100 years). This relationship reflects a clear causal pathway between emissions and expected warming. The connection between worker hours and forced labor is not causal; however, the amount of worker hours required to produce a product is a compelling variable to use to scale and compare risk.

We adapted the SHDB social impact assessment method, using the following conversion factors: Very High Risk = 10, High Risk = 5, Medium Risk = 1, Low Risk = 0.01 mrh eq, Very Low Risk = 0.001 mrh eq. These factors reflect the relative probability that an adverse situation will occur across all social risk categories in the database.[16] The Very Low Risk level was added to match our coding and higher resolution data; it is not found in the SHDB. Because commodities had multiple origin countries, weighted means and ranges of forced labor risk were calculated.

Hotspot analysis of fruit and vegetable supplies

In addition to risk per serving, we assessed risk at the level of the national per capita annual fruit and vegetable supplies to identify risk hotspots. We assess supply at the level of retail availability, which includes the total quantity available for sale at retail outlets in the US. Retail availability for each commodity included the following fractions using the LAFA data series: 1) retail waste or loss and 2) food purchased. This approach allows us to explore the embedded social risk that is wasted or lost on the demand side of the supply chain.

Retail availabilities of commodities (lb capita^{-1} year^{-1})[49] were multiplied by retail prices[51] to estimate retail availability of each commodity in dollars. Prices were adjusted using a margin multiplier and commodity-specific risk was calculated, following the same procedure as in calculating per serving risk.

Data Availability

Results data generated during the study and select input data are available in the supplementary materials. All other data are available from the corresponding author upon reasonable request.

Code Availability

R code supporting this study is available from the corresponding author.

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Table 1: Qualitative coding of forced labor risk levels

Risk level	Known Occurrences (85% of score)			Government Response[4] (15% of score)
	Step 1: Commodity-Country[1]	Step 2: Sector-Country[2]	Step 3: Country[3]	
Very high	Commodity reportedly produce with forced labor; at least one account of forced labor	NA	NA	Tier 3 rank
High	Commodity is hand-harvested and evidence of sector-country risk exists	Forced labor, debt bondage or labor trafficking occurs in the sector	>0.70% of people enslaved	Tier 2W rank
Medium	Concern/indicators of risk present	At least one account or report of forced labor, debt bondage, or trafficking for labor in the sector	>0.30% of people enslaved	Tier 2 rank
Low	NA	Concern/indicators of risk present	>0.20% of people enslaved	Tier 1 rank
Very Low	NA	NA	<0.19% of people enslaved	NA

1. Sources: Verite (2017; 2018); US DoL List of Goods (2018); ERS (2010); Martin and Taylor (2013); Guilliam (2018); Rees (n.d.); MASIPAG (2015); USITC (2001); FDA and UC Davis (n.d.), Calvin and Martin (2010)
2. Sources: US DoS HRR (2018) & US DoS TIP (2019)
3. Sources: GSI (2016)
4. Sources: US DoS TIP (2019)

Table 2: Examples of forced labor in the agricultural sector

ILO indicators of forced labor[1]	**Example(s)**
Abuse of vulnerability	Migrant communities from Central and South America, fleeing persecution and economic hardship, by searching for work opportunities (e.g. Honduras, Venezuela). Seasonal migrant workers/casual laborers.
Deception	Coercion and false information, particularly during the recruitment process.
Restriction of movement	Lack of freedom of movement; inability to leave the farm.
Retention of identity documents	Removal of passports and working permits. Employment of undocumented workers.
Isolation	Remote farm locations. Removal of communication devices.
Physical and sexual violence	Sexual harassment. Violence and the threat of violence.
Intimidation and threats	Threat of deportation for undocumented workers.
Abusive working and living conditions	Lack of decent work – long hours, increased heat stress, inability to take breaks. Changing climatic conditions likely to increase risks moving forward e.g. air pollution inhalation and increased heat stress of agricultural workers from wildfires.
Withholding of wages	Piece-rate payments, wages tied to productivity. Wages not paid until the end of an employment period.
Debt bondage	Deduction of wages to cover costs of permits, accommodation, food and living expenses.
Excessive overtime	Minimal or no additional pay for involuntary and long work hours beyond those contracted.

1. Source: ILO (2012)[57]

Figure 1: Weighted mean, maximum, and minimum estimated risk of forced labor per serving of fruits consumed in the US

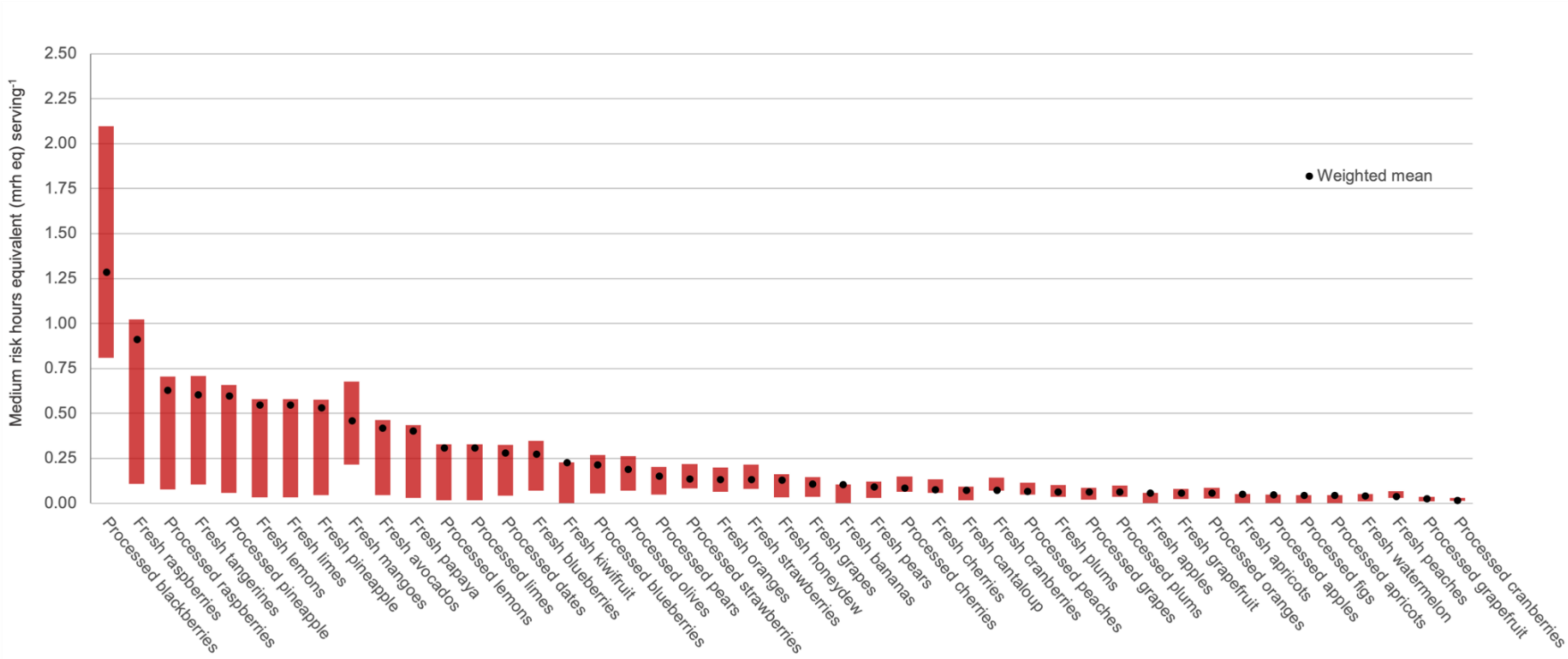

Figure 2: Weighted mean, maximum, and minimum estimated risk of forced labor per serving of vegetables consumed in the US

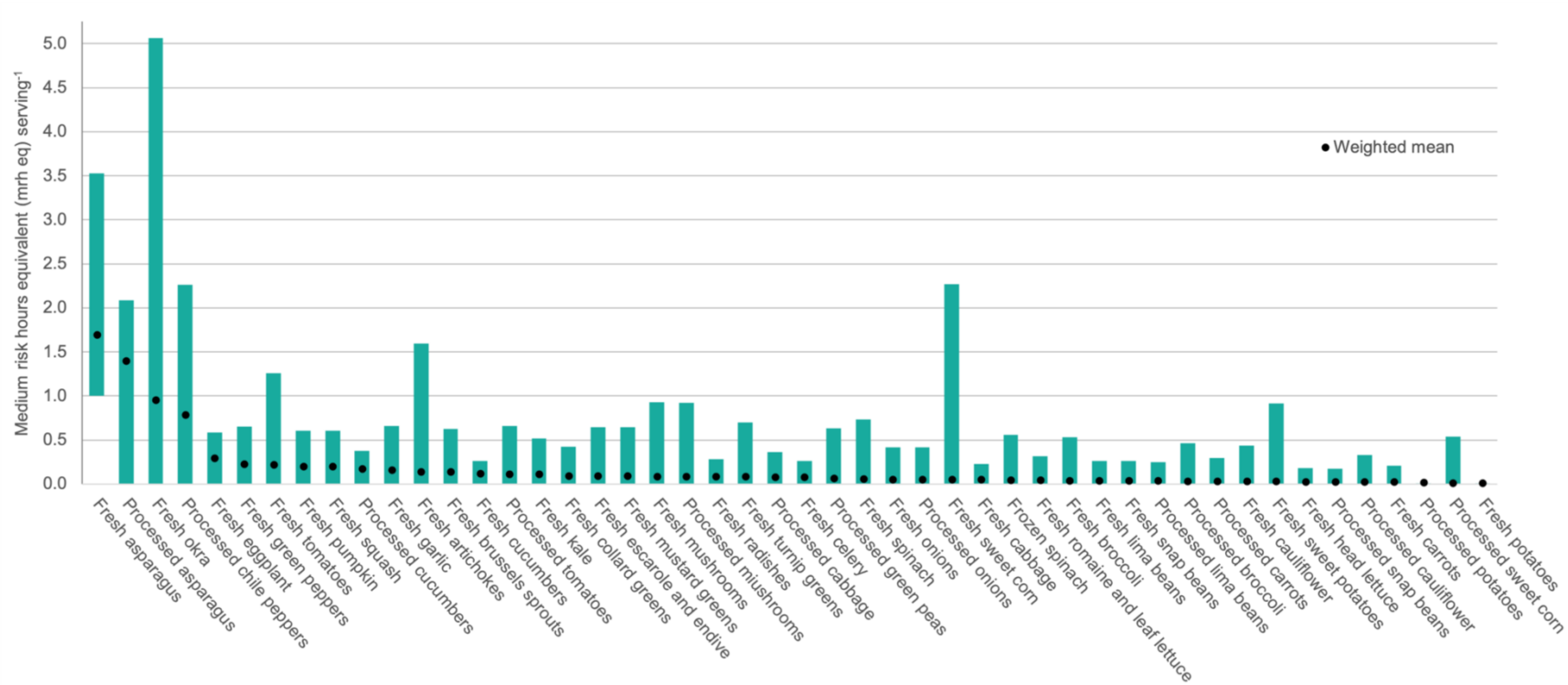

Figure 3: Top five items as proportion of total forced labor risk in retail fruit and vegetable supply