

# Estimating Occupational Illness, Injury, and Mortality in Food Production in the United States

## *A Farm-to-Table Analysis*

Kira L. Newman, BA, Juan S. Leon, PhD, MPH, and Lee S. Newman, MD, MA

**Objectives:** The study provides a novel model and more comprehensive estimates of the burden of occupational morbidity and mortality in food-related industries, using a farm-to-table approach. **Methods:** The authors analyzed 2008 to 2010 US Bureau of Labor Statistics data for private industries in the different stages of the farm-to-table model (production, processing, distribution and storage, and retail and preparation). **Results:** The morbidity rate for food system industries was significantly higher than the morbidity rate for nonfood system industries (rate ratio = 1.62; 95% confidence interval = 1.30 to 2.01). Furthermore, the occupational mortality rate for food system industries was significantly higher than the national nonfood occupational mortality rate (rate ratio = 9.51; 95% confidence interval = 2.47 to 36.58). **Conclusions:** This is the first use of the farm-to-table model to assess occupational morbidity and mortality, and these findings highlighting specific workplace hazards across food system industries.

Recent interest in infectious and noninfectious foodborne disease outbreaks has brought increasing public attention to food production, processing, and preparation.<sup>1</sup> Nevertheless, the focus has largely been on consumer illness and death, with less attention paid to worker health and safety. Overall, the annual economic burden of occupational morbidity and mortality in the United States is estimated to be approximately \$250 billion, including direct and indirect costs.<sup>2</sup> Many industries related to food production, including agriculture, manufacturing, and food preparation, have high occupational morbidity rates.<sup>3,4</sup> Food production workers, especially those engaged in fishing, hunting, and trapping, have the highest rate of

### Learning Objectives

- Discuss the researchers' rationale and methods for using a farm-to-table approach to estimate the burden of occupational morbidity and mortality in food-related industries.
- Summarize the reported morbidity and mortality rates for food system industries, including comparisons between sectors within the food industry and with non-food system industries.
- Discuss the study implications for assessing and addressing specific occupational hazards associated with each step in the farm-to-table continuum.

job-related fatalities in the United States, compared with other private industry workers.<sup>5-7</sup> A large body of literature exists regarding occupational morbidity and mortality during food production,<sup>8-10</sup> but the health of workers in food-related industries is less studied. We are not aware of any systematic attempts to calculate the combined burden of worker injury and illness associated with feeding an industrialized nation.

The farm-to-table framework for understanding the pathways and processes necessary for modern food has been widely used in microbial risk assessment,<sup>11,12</sup> food safety education,<sup>13</sup> contextualization of outbreaks,<sup>14,15</sup> and popular discussion of food-related issues<sup>16</sup> pertaining to consumers. In this article, we use the farm-to-table continuum (sometimes referred to as the food system) as a heuristic for organizing categories of food system industries to better understand the impact of food production on worker health. The five major steps in the model are food creation, processing, distribution and storage, retail, and preparation (Fig. 1).<sup>17,18</sup> Between and within each step, there are transportation and the creation of waste. We have included transportation that occurs within steps along the farm-to-table continuum (eg, on farms or in processing centers) though transportation between steps has not been (eg, the transportation industry). We did not include industries that manage food waste in this analysis because they are not traditionally part of the farm-to-table continuum. Although different commodities follow diverse paths en route to consumers, the farm-to-table model provides a broad framework with which to capture the diverse paths to the consumer and may be stratified later by industry or food, as necessary. To present a more integrated perspective of the impact of modern food production and processing on worker health, we sought to calculate estimates of the increased burden of occupational illness, injury, and death related to each stage in the farm-to-table continuum, a conceptual model of the food system.

### METHODS

We used morbidity and mortality data from private industries included in the US Bureau of Labor Statistics' (BLS) Illnesses Injuries and Fatalities program's Survey of Occupational Injuries and Illnesses (SOII)<sup>19-21</sup> and the Census of Fatal Occupational Injuries (CFOI).<sup>5-7</sup> Survey of Occupational Injuries and Illnesses is a federal

From the Department of Epidemiology (Ms Newman), Rollins School of Public Health and Laney Graduate School; Hubert Department of Global Health (Dr Leon), Rollins School of Public Health, Emory University, Atlanta, Ga; and Center for Worker Health and Environment (Dr Newman), Colorado School of Public Health and School of Medicine, University of Colorado Denver, Anschutz Medical Campus, Aurora.

This work was supported by funding from the ARCS Foundation and by the National Institute of Diabetes And Digestive and Kidney Diseases of the National Institutes of Health (F30DK100097) to KLN. This work was partially supported by the National Institute of Allergy and Infectious Diseases at the National Institutes of Health (grant 1K01AI087724-01), the National Institute of Food and Agriculture at the US Department of Agriculture (grant 2010-85212-20608), and the Emory University Global Health Institute to JSL. This work was supported in part by grant T42OH009229, funded by the Centers for Disease Control and Prevention, to LSN. The content is solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health, the Centers for Disease Control and Prevention, or the Department of Health and Human Services.

Authors Newman, Leon, and Newman have no relationships/conditions/circumstances that present potential conflict of interest.

The JOEM editorial board and planners have no financial interest related to this research.

Supplemental digital contents are available for this article. Direct URL citations appear in the printed text and are provided in the HTML and PDF versions of this article on the journal's Web site ([www.joem.org](http://www.joem.org)).

Address correspondence to: Department of Epidemiology, Rollins School of Public Health and Laney Graduate School, Emory University, 1518 Clifton Rd, NE, Atlanta, GA 30322 ([kira.newman@emory.edu](mailto:kira.newman@emory.edu)).

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DOI: 10.1097/JOM.0000000000000476

and state program in which approximately 176,000 private industry establishments provide annual reports on the number of injuries and illnesses each employer has recorded in their logs. Nonfatal occupational injuries are reportable if they cause lost work time, require medical treatment other than first aid, restrict work or motion, cause loss of consciousness, require transfer to another job, or meet other criteria outlined by the Occupational Safety and Health Administration.<sup>22</sup> The CFOI is a nation-wide program that compiles death counts using state and federal sources including death certificates, workers' compensation reports, and administrative reports.<sup>23</sup> Deaths because of traumatic injuries for which exposures or actions that occurred as part of an employee's work-related activities during a single workday or shift are eligible for inclusion, though deaths during commuting are excluded. The CFOI does not include fatal occupational illnesses. Deaths are reported to the BLS by states, and the final data set is compiled by cross-referencing various source materials, including reports by other agencies.

We analyzed the morbidity and mortality data from private industry from 2008 to 2010, the most recent years with final corrected data available, to estimate illness, injury, and fatality rates. We used employment numbers from the BLS's National Industry Employment Estimates and National Occupational Employment and Wage Estimates included with each year's SOII.<sup>19-21</sup> Industries explicitly involved in food production, processing, storage, retail, and preparation were included (Table 1). We chose to group both wholesale and retail businesses in the food-related retail category. For food production stage-level categories (ie, production and processing), we calculated injury and fatality rates by dividing each industry's counts by their total employment. Food-specific transportation statistics were not available, so transportation was not included in estimates for distribution and storage stage industries. We excluded food-related industries to calculate non-food private industry morbidity and mortality rates (Supplementary Table 1, <http://links.lww.com/JOM/A203>). Rates from industries from within the same farm-to-table stage were averaged together, weighted by employment, to get a group rate. To compare rates between groups, we used Wald tests after fitting negative binomial regression models with general estimating equations (GEE). We used negative binomial models for all analyses and reported medians because diagnostic analyses indicated overdispersion and nonnormal distribution. We used GEE to control for year-to-year correlation within industries. We specified the contrast statements to obtain estimated rate ratios (RRs). We also estimated excess morbidity and mortality by calculating the difference between observed food industry counts of illnesses, injuries, and deaths and the number expected by applying mean nonfood industry morbidity and mortality rates for each industry sector to food industry employment numbers from the same sector.

First, we compared the occupational morbidity and mortality rates for non-food-producing private industries with food system occupational morbidity and mortality rates. Second, we compared industry sector-specific occupational mortality and morbidity rates with food system occupational mortality and morbidity rates. For example, we compared food production worker morbidity rates with

the national rate for goods-producing industries. Third, we assessed specific causes of any differences in morbidity or mortality rates by comparing event-specific injury and fatality data. Lastly, we compared separate rates for industries producing and processing meat, fish, and dairy (collectively referred to as meat) products and industries producing and processing nonmeat, nondairy products to assess for possible product-specific effects.

Models comparing food system and nonfood system industries included a variable to distinguish between the categories, as did models comparing meat and nonmeat industries. All analyses were conducted in SAS 9.3 (Cary, NC) with a significance level of 0.05.

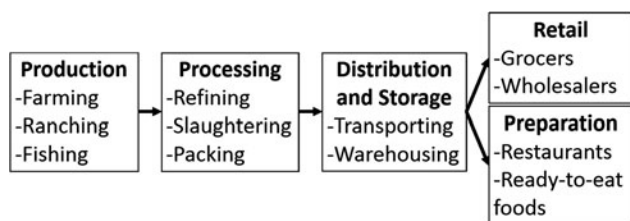
## RESULTS

From our analyses, food system jobs, excluding individuals employed in transportation, make up an estimated 15% of all private industry jobs in the United States. We excluded individuals employed in transportation because no numbers were available for the proportion of laborers employed in food-specific transportation. As measured by the number of total food industry workers, food service (59.28%), retail (23.74%), and processing (10.96%) were

**TABLE 1.** Food-Related Industries Included in the Analysis and Their Annual Average Employment, US Bureau of Labor Statistics, 2008 to 2010

Industries Included in the Analysis, Grouped by Farm-to-Table Stage	NAICS* Code	Average Employment (Thousands)
All nonfood private industry		90,147.2
Food production		
Crop production	111	416.5
Animal production	112	161.4
Fishing, hunting, and trapping	114	8.8
Support activities for agriculture and forestry	115	332.6
Food processing		
Food manufacturing	311	1,467.3
Beverage and tobacco product manufacturing	312	193.6
Pesticide, fertilizer, and other agricultural chemical manufacturing	3253	36.5
Agricultural implement manufacturing	33311	75.4
Food storage		
Refrigerated warehousing and storage	49312	48.7
Farm product warehousing and storage	49313	9.0
Food retail		
Grocery and related product merchant wholesalers	4244	725.6
Farm product raw material merchant wholesalers	4245	74.0
Beer, wine, and distilled alcoholic beverage merchant wholesalers	4248	162.7
Food and beverage stores	445	2,876.4
Food service		
Food services and drinking places	722	9,586.2

\*North American Industry Classification System.



**FIGURE 1.** Schematic of pathway of food from farm to table with examples of generic industry categories within each stage.

**TABLE 2.** Morbidity Rate, Mortality Rate, and Rate Ratios Comparing Morbidity and Mortality Rates for Food System Jobs by Farm-to-Table Stage to Same-Sector Nonfood Private Industry Morbidity and Mortality Rates, US Bureau of Labor Statistics, 2008 to 2010

Industry	Median Morbidity Rate* (IQR)	RR (95% CI)	Median Mortality Rate† (IQR)	RR (95% CI)
All nonfood industry	2.65 (1.62–4.00)	Reference‡	0.17 (0.09–0.33)	Reference
All food industry	2.33 (2.16–4.17)	1.62 (1.30–2.01)	0.13 (0.12–0.28)	9.51 (2.47–36.58)
Production to retail				
Nonfood	2.33 (1.66–3.97)	Reference	0.13 (0.09–0.33)	Reference
Food	4.17 (3.83–5.74)	1.71 (1.39–2.10)	0.33 (0.28–0.47)	10.28 (2.68–3.45)
Production				
Nonfood	2.34 (2.16–3.83)	Reference	1.18 (1.15–1.24)	Reference
Food	4.00 (3.58–4.06)	1.30 (0.82–2.06)	7.17 (1.42–7.76)	6.50 (1.49–28.44)
Processing				
Nonfood	4.61 (2.90–5.64)	Reference	0.22 (0.16–0.29)	Reference
Food	5.74 (5.70–6.25)	1.34 (0.97–1.85)	0.39 (0.33–0.47)	1.75 (1.10–2.77)
Storage§				
Nonfood	5.45 (5.40–6.20)	Reference	1.43 (1.31–1.56)	Reference
Food	7.02 (6.56–7.58)	1.19 (1.04–1.35)	1.24 (1.02–1.24)	11.89 (5.35–26.42)
Retail				
Nonfood	3.49 (1.63–4.49)	Reference	0.29 (0.09–0.33)	Reference
Food	3.83 (3.83–4.17)	1.90 (1.38–2.61)	0.28 (0.19–0.31)	2.72 (1.10–6.71)
Service				
Nonfood	1.81 (0.94–3.10)	Reference	0.10 (0.08–0.26)	Reference
Food	2.16 (2.07–2.33)	0.95 (0.74–1.21)	0.12 (0.12–0.13)	0.42 (0.26–0.68)

\*Reported injuries and illnesses per 100 full-time workers, weighted on the basis of average annual employment.

†Reported fatal occupational injuries per 10,000 full-time workers, weighted on the basis of average annual employment.

‡Estimates from negative binomial GEE models.

§Excludes distribution and does not include retail storage.

||Excludes transportation.

CI, confidence interval; IQR, interquartile range; RR, rate ratio.

the first, second, and third most populous steps in the farm-to-table continuum. Storage had the highest median morbidity level among the steps in the farm-to-table continuum (7.02 annual cases/100 full-time workers; Table 2), and production had the highest mortality level (7.17 deaths/10,000 full-time workers; Table 2).

When comparing within the industry category, there was still a significant difference between morbidity rates in food-producing industries and non-food-producing industries (Table 2). Food production industries had a higher rate of injuries and illnesses than the rate for all goods-producing industries, and food processing industries had a slightly higher rate of injuries and illnesses than did manufacturing industries overall, though neither was significant (RR = 1.30,  $P = 0.269$ ; RR = 1.34,  $P = 0.073$ , respectively). Food storage industries had a significantly higher morbidity rate than other storage industries (RR = 1.19,  $P = 0.002$ ). Food retail industries had a significantly higher rate of injuries and illnesses than did other types of retail industries (RR = 1.90,  $P < 0.001$ ). Food service industries had a similar occupational morbidity rate to other same-sector nonfood industries.

In addition to having higher morbidity rates overall, food system industries as a whole had a higher rate of more severe injuries—those requiring days away from work—compared with nonfood private industries overall (RR = 2.38,  $P = 0.005$ ; Table 3). This did not seem to be driven by any specific industry sector with inordinately higher rates than the other industry sector, as food industries in all sectors except food service had higher rates of severe injuries than same-sector nonfood industries (Table 3). Food processing, storage, and retail industries—all had significantly higher rates of injuries and illnesses requiring days away from work compared with non-

food private industries from the same sectors ( $P = 0.042$ ,  $P = 0.009$ , and  $P < 0.001$ , respectively). Conversely, food service industries had a significantly lower rate of severe injuries than all nonfood private industries (RR = 0.75,  $P = 0.029$ ).

The higher rate of injuries and illnesses requiring days away from work among food system industries compared with non-food system industries was mostly due to industry sector-specific differences rather than intersector patterns of morbidity differences between food and nonfood industries (Supplementary Fig. 1, <http://links.lww.com/JOM/A203>). Nevertheless, the rates of severe injuries from contact with an object or equipment and slips, trips, and falls were elevated among all sectors of food industries compared with nonfood industries, with the exception of food service industries (Table 3). Workers in food production industries were significantly more likely to be injured severely by assault by a person ( $P = 0.002$ ) and assault by other causes, including animals or insects ( $P < 0.001$ ) than workers in nonfood production industries were. Workers in food processing industries were significantly more likely to be severely injured by a slip, trip, or fall ( $P = 0.002$ ); exposure to harmful substances ( $P = 0.044$ ); and transportation incidents ( $P = 0.002$ ) than workers in nonfood manufacturing industries. Food storage and food retail industries had higher rates of severe injuries compared with nonfood storage and retail industries, and this was reflected in significantly higher rates of most categories of severe injury events (Table 3). Workers in food service industries were less likely than workers in other service industries to be severely injured, and this extended to most categories of severe injury events, with the exception of injuries from exposure to harmful substances (RR = 2.10,  $P < 0.001$ ).

**TABLE 3. Severe Injury and Illness Rate and Rate Ratios Comparing Severe Injury and Illness Rates for Food System Jobs by Farm-to-Table Stage to Same-Sector Nonfood Private Industry Severe Injury and Illness Rates for Specific Injury and Illness Causes, US Bureau of Labor Statistics, 2008 to 2010**

Industry	Median Severe Injury Rate* (IQR)	Contact With		Slips, Trips, and Falls		Overexertion RR (95% CI)	Repetitive Motion RR (95% CI)	Exposure to Substances or Environment		Transportation Incident		Assault by Person		Assault by Other	
		Severe Injury RR (95% CI)	Object or Equipment RR (95% CI)	Falls RR (95% CI)	RR (95% CI)			RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)	RR (95% CI)
All nonfood industry	0.82 (0.48–1.25)	Reference‡	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	
All food industry	0.56 (0.53–1.24)	2.38 (1.38–4.08)	2.43 (1.43–4.14)	1.08 (1.33–3.24)	2.56 (1.20–5.45)	1.78 (0.83–3.80)	1.68 (1.12–2.52)	2.75 (1.18–6.40)	0.76 (0.26–2.20)	8.73 (2.35–32.40)					
Production to retail															
Nonfood	0.67 (0.49–1.18)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	
Food	1.29 (1.13–1.43)	2.55 (1.49–4.37)	2.60 (1.53–4.42)	2.19 (1.40–3.43)	2.81 (1.32–5.96)	1.94 (0.91–4.15)	1.64 (1.06–2.53)	3.04 (1.31–7.03)	0.71 (0.23–2.20)	9.42 (2.55–3.75)					
Production															
Nonfood	1.44 (1.20–1.50)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	
Food	1.29 (1.20–1.52)	1.22 (0.78–1.91)	1.27 (0.81–2.00)	1.10 (0.59–2.05)	0.68 (0.36–1.28)	1.41 (0.76–2.61)	1.49 (0.74–3.03)	0.87 (0.42–1.82)	9.26 (2.20–38.92)	28.98 (5.67–148.18)					
Processing															
Nonfood	1.09 (0.73–1.30)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Ref	
Food	1.40 (1.31–1.43)	1.38 (1.01–1.89)	1.16 (0.74–1.83)	1.54 (1.18–2.00)	1.61 (0.98–2.64)	0.90 (0.52–1.57)	1.61 (1.01–2.56)	3.11 (1.50–6.44)	1.74 (0.26–11.44)	3.69 (0.93–14.64)					
Storage§															
Nonfood	1.55 (1.48–1.87)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	
Food	2.58 (2.54–25.37)	4.06 (1.70–9.72)	4.35 (1.77–10.67)	4.15 (2.45–7.02)	3.48 (1.08–11.17)	3.23 (0.75–13.92)	4.32 (1.09–17.21)	4.10 (1.03–16.27)	Not estimated¶	Not estimated¶					
Retail															
Nonfood	1.00 (0.67–1.13)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	
Food	1.24 (1.08–1.44)	2.22 (1.51–3.27)	2.21 (1.58–3.09)	1.88 (1.39–2.53)	2.58 (1.20–5.56)	2.12 (1.29–3.48)	0.92 (0.52–1.62)	2.26 (1.06–4.84)	1.60 (0.45–5.69)	7.13 (1.13–44.76)					
Service															
Nonfood	0.59 (0.31–1.04)	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	Reference	
Food	0.53 (0.49–0.56)	0.75 (0.59–0.97)	1.13 (0.83–1.53)	0.78 (0.62–0.99)	0.49 (0.34–0.70)	0.52 (0.42–0.65)	2.10 (1.57–2.80)	0.21 (0.14–0.33)	0.59 (0.27–1.31)	0.04 (0.03–0.07)					

\*Reported injuries requiring days away from work per 100 full-time workers, weighted on the basis of average annual employment.

†Includes unintentional assault by a person or assault by an animal or insect.

‡Estimates from negative binomial GEE models.

§Excludes distribution and does not include retail storage.

||Excludes transportation.

¶Not estimated because the model did not converge because of small numbers of events.

CI, confidence interval; IQR, interquartile range; RR, rate ratio.

There was a significantly higher mortality rate for workers in food system industries than for those in all nonfood private industries, though the effect estimate was imprecise ( $RR = 9.51$ ,  $P = 0.002$ ; Table 2). When comparing within industry sector, food production, processing, storage, and retail industries had higher mortality rates than their nonfood system counterparts ( $P = 0.013$ ,  $P = 0.017$ ,  $P < 0.001$ , and  $P = 0.030$ , respectively). Food service industries had a significantly lower mortality rate than same-sector nonfood industries ( $RR = 0.42$ ,  $P < 0.001$ ).

Elevated rates of fatal occupational injuries among food production and food processing industries as compared with nonfood production and manufacturing industries, respectively, were due to significantly higher rates of fatal transportation injuries, fatal assaults (includes assaults by people and other animals), and fatal exposures to substances or environments (Table 4; Supplementary Fig. 2, <http://links.lww.com/JOM/A203>). Elevated fatal injury rates for food retail industries compared with nonfood retail industries were due to higher rates of fatal transportation incidents, assaults, and fatal injuries from contact with objects or equipment, though the only significantly elevated cause of fatal injuries was from contact with objects or equipment ( $P = 0.012$ ). Compared with nonfood service industries, food service industries had significantly lower rates of mortality because of all causes considered, except for fatal assaults.

On the basis of nonfood industry sector-specific mean morbidity and mortality, food industries had an estimated 57,975 excess injuries and illnesses and 439 excess deaths annually (subsequent results in Supplementary Table 2, <http://links.lww.com/JOM/A203>). The greatest numbers of excess injuries and illnesses were in food processing and retail. Food processing had 28,436 estimated excess injuries and illnesses, and food retail had an estimated 48,717 estimated excess injuries and illnesses. The greatest numbers of excess fatalities were in food production and processing. Food production had 408 estimated excess deaths, and food processing had 59 estimated excess deaths. Food service was the only farm-to-table stage without excess morbidity and mortality. Food service industries had 27,216 fewer injuries and illnesses than expected and 64 fewer deaths than expected, compared with the mean rates from other service industries.

Industries related primarily to meat, fish, and dairy production and processing did not have significantly higher morbidity rates than industries related to produce and other nonmeat food production and processing ( $RR = 1.15$ ,  $P = 0.303$ ; Supplementary Table 3, <http://links.lww.com/JOM/A203>). Nevertheless, meat-related food industries had a significantly higher rate of injuries requiring days away from work compared with nonmeat food production and processing industries ( $RR = 1.40$ ;  $P = 0.008$ ; Supplementary Table 3, <http://links.lww.com/JOM/A203>). Workers in meat-related industries were significantly more likely to be severely injured by contact with an object or equipment ( $RR = 1.50$ ,  $P = 0.005$ ; Supplementary Table 3, <http://links.lww.com/JOM/A203>), but the largest driver of the difference in severe injury rates was assaults by people and other animals ( $RR = 16.80$ ,  $P = 0.002$ ; Supplementary Table 3, <http://links.lww.com/JOM/A203>). In addition, meat, fish, and dairy-related industries had a much higher mortality rate compared with non-meat-related food industries ( $RR = 7.33$ ,  $P = 0.020$ ; Supplementary Table 3, <http://links.lww.com/JOM/A203>). This was due to a higher rate of fatalities because of assaults by people or other animals ( $RR = 9.22$ ,  $P = 0.001$ ; Supplementary Table 3, <http://links.lww.com/JOM/A203>) and fatal exposures to substances or environments ( $RR = 21.67$ ,  $P = 0.003$ ; Supplementary Table 3, <http://links.lww.com/JOM/A203>).

## DISCUSSION

The purpose of this research is to provide a novel model and estimates of the burden of occupational illness, injury, and death in

food-related industries in the United States, using a farm-to-table approach. Food industries, especially those involved in processing, storage, and retail, have significantly higher rates of illnesses and injuries, as compared with nonfood private industries in the United States. We observed a pattern of elevated rates of morbidity across most of the farm-to-table continuum, underscoring the need for concerted action to reduce unnecessary injuries and illnesses across this diverse industry spectrum. We also observed significantly elevated rates of occupational mortality in food production, processing, and retail.

## Occupational Morbidity

The morbidity rate for food system industries along the farm-to-table spectrum was higher in all sectors, except food service, when compared with nonfood industries. Even when compared with industries from the same category (eg, workers employed by industries processing other types of products) to make a comparison between more similar industries, food system industries generally had higher rates of occupational injury and illness than their same industry sector counterparts. Potential workforce and process-related reasons for this finding merit future research.

From a workforce standpoint, these industries may have different job requirements, there may be different safety procedures in place with different levels of adherence, there may be geographic differences in the workforce, and there may be different experience levels, differential vulnerabilities, or differences in the language or culture of the workforces. Food system workforces often are demographically different from the general population and the jobs themselves are distinct.<sup>24</sup> Food system workers also tend to be younger than other workers in similar occupational categories,<sup>25</sup> and younger workers tend to have higher rates of injuries than older workers,<sup>26</sup> though this may be a surrogate for being newly hired and having less training and experience. There may also be socioeconomic differences. Eight of the 10 lowest-paying occupations in the United States are food system jobs, suggesting that workers in these industries may be uniquely disadvantaged.<sup>27</sup> Within the manufacturing sector, all manufacturing industries (eg, chemical manufacturing and furniture manufacturing) except textile and apparel manufacturing have higher mean and median hourly wages than food manufacturing.<sup>28</sup> Some workforce-related causes of higher rates of occupational morbidity may be amenable to change by improved training, and there are successful programs that have been developed to target food industry workers.<sup>29</sup> One example is severe injuries because of contact with objects or equipment. All food-related industries except for food service had higher rates of severe injuries because of contact with objects or equipment than nonfood industries from the same sectors. Lack of experience with a particular task has been associated with higher rates of machinery-related injury among farmworkers and meatpackers,<sup>30,31</sup> suggesting that increased training may reduce injury rates. Nevertheless, hazards related to equipment can also vary by the equipment provided and other process-related factors.<sup>32</sup>

Process-related reasons for differences in occupational morbidity include differences in the activities and occupational practices of food-related industries compared with non-food-related industries. Our data indicate that the differences between causes of severe injuries among food system industries and nonfood system industries from the same sector vary. Some of these differences are indicative of unique job responsibilities or conditions. For example, workers in food production industries (eg, ranchers and fishermen) are more likely to be severely injured by animals compared with workers in non-food production industries (eg, miners and forestry workers). There are also different working environments required when food is present. One possible reason for significantly elevated rates of severe injuries because of slips, trips, and falls in food processing, storage, and retail industries compared with nonfood same-sector industries may be the preponderance of refrigeration.<sup>33</sup> Many food

**TABLE 4. Mortality Rate and Rate Ratios Comparing Severe Injury Rates for Food System Jobs by Farm-to-Table Stage to Same-Sector Nonfood Private Industry Severe Injury Rates for Specific Injury Causes, US Bureau of Labor Statistics, 2008 to 2010**

Industry	Median Mortality Rate* (IQR)	Mortality RR (95% CI)	Transportation RR (95% CI)	Assault RR (95% CI)	Contact With Object or Equipment RR (95% CI)	Slip, Trip, Fall RR (95% CI)	Exposure to Substance or Environment RR (95% CI)	Fire or Explosion RR (95% CI)
All nonfood industry	0.17 (0.09–0.33)	Reference†	Reference	Reference	Reference	Reference	Reference	Reference
All food industry	0.13 (0.12–0.28)	9.51 (2.47–36.58)	19.61 (3.91–98.29)	5.11 (1.92–13.59)	4.30 (1.09–16.94)	2.44 (0.67–8.90)	16.75 (3.25–86.45)	1.13 (0.29–4.31)
Production to retail								
Nonfood	0.13 (0.09–0.33)	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Food	0.33 (0.28–0.47)	10.28 (2.68–39.45)	21.30 (4.26–106.39)	5.35 (1.98–14.49)	4.67 (1.18–18.43)	2.67 (0.73–9.72)	18.18 (3.53–93.71)	1.23 (0.33–4.65)
Production								
Nonfood	1.18 (1.15–1.24)	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Food	7.17 (1.42–7.76)	6.50 (1.49–28.44)	14.79 (3.10–70–63)	20.76 (6.95–62.00)	1.66 (0.39–7.17)	2.00 (0.59–6.78)	9.67 (2.17–43.12)	0.68 (0.22–2.09)
Processing								
Nonfood	0.22 (0.16–0.29)	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Food	0.39 (0.33–0.47)	1.75 (1.10–2.77)	2.78 (1.16–6.63)	2.10 (1.17–3.77)	0.40 (0.10–1.65)	1.12 (0.32–4.01)	2.55 (1.36–4.78)	0.60 (0.11–3.23)
Storage‡								
Nonfood§	1.43 (1.31–1.56)	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Food	1.24 (1.02–1.24)	11.89 (5.35–26.42)	Not estimated	Not estimated	Not estimated	Not estimated	Not estimated	Not estimated
Retail								
Nonfood	0.29 (0.09–0.33)	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Food	0.28 (0.19–0.31)	2.72 (1.10–6.71)	2.51 (0.90–6.94)	1.33 (0.52–3.39)	9.55 (1.64–55.62)	0.95 (0.45–2.00)	0.34 (0.08–1.37)	Not estimated
Service								
Nonfood	0.10 (0.08–0.26)	Reference	Reference	Reference	Reference	Reference	Reference	Reference
Food	0.12 (0.12–0.13)	0.42 (0.26–0.68)	0.14 (0.08–0.28)	1.38 (0.87–2.22)	0.09 (0.03–0.22)	0.48 (0.29–0.79)	0.44 (0.26–0.72)	Not estimated

\*Reported fatal occupational injuries per 10,000 full-time workers, weighted on the basis of average annual employment.

†Estimates from negative binomial GEE models.

‡Excludes distribution and does not include retail storage.

§Excludes transportation.

||Not estimated because the model did not converge because of small numbers of events.

CI, confidence interval; IQR, interquartile range; RR, rate ratio.

products are processed and stored at cooler temperatures to maintain freshness, and this can lead to precipitation that may make floors slippery<sup>34</sup> in factories, warehouses, or on-site storage areas in retail facilities.<sup>35</sup>

In estimating product-specific morbidity rates, meat, fish, and dairy production and processing industries did not have significantly higher rates of occupational injury and illness than nonmeat, nondairy production, and processing industries. Nevertheless, the illnesses and injuries were more severe, suggesting that some of the differences in rates of severe injuries and illnesses between food and nonfood industries may be driven by a subset of all food industries.

## Occupational Mortality

Although occupational fatalities are relatively rare events, the overall food industry mortality rate is high when compared with the occupational mortality rate for nonfood private industries, with the exception of food service industries. The increased risk of mortality in food production industries has also been established by other researchers.<sup>36,37</sup>

The fatal injuries in food production and food processing industries are largely the result of transportation incidents, assaults, and exposure to toxic substances or environments. In many food system industries, practices to prevent occupational fatalities exist, though they are not consistently used. Use that differs within an industry may be associated with occupational health disparities.<sup>37</sup> For example, though tractor roll-over fatalities are a well-documented hazard for agricultural workers, only an estimated 59% of tractors in operation are equipped with roll-over protection,<sup>38</sup> and the prevalence of such protection is lower among lower-income farmers.<sup>36,39</sup> Whether causes of fatal injuries across other food-related industry sectors are due to similar shortcomings in safety equipment, protocols, and training is an important topic for future research.

The only farm-to-table stage that did not show higher rates of occupational mortality was food service. Food service industries had significantly lower rates of occupational fatalities than other service industries. Food service workers were less likely to die of all causes considered, with the exception of assaults. Although it was not statistically significant, food service industries had a higher rate of fatal assaults than other service workers. This finding was consistent with earlier work.<sup>40</sup> The lower rate of fatal occupational injuries by all other documented causes is likely because food service occurs in a controlled environment, relative to some other service industries. Although the food service environment is a common source of injury, these injuries are rarely severe enough to result in death.

In estimating product-specific mortality rates, meat, fish, and dairy production and processing industries had significantly higher rates of fatal occupational injuries than nonmeat, nondairy production, and processing industries. This is consistent with the known hazards of meat-producing industries, such as fishing, hunting, and trapping and animal production, which have the first and third highest mortality rates of all private industries.<sup>5-7</sup>

## Limitations

Because of limited information regarding transportation and storage of food products, transportation jobs were not included in farm-to-table morbidity and mortality estimates. Transportation accidents are a common cause of injury and death in other industries, so the exclusion of these industries from our calculations likely resulted in an underestimate of the full impact across the continuum. An additional area of uncertainty relates to the farm-to-table model's own limits. An estimated 40% of the American food supply goes uneaten,<sup>41</sup> making industries responsible for the disposal of food waste a potentially important area to consider to capture all occupational morbidity and mortality related to food. Nevertheless, the impact of this "posttable" stage of waste management was not assessed in our study. In addition, some categories include both

food and nonfood industries, leading to some misclassification in our analysis. For example, refrigerated storage and warehousing includes storage of furs though we categorized it as a food-related industry because of the major role it plays in the storage of food ts.

Another limitation of this work is the lack of product-level data. This restricted the degree to which specific illnesses or injuries could be linked to a specific product type, though we attempted to estimate these differences in general product categories by comparing meat and non-meat-producing industries. We restricted our analysis to private industry, and therefore this analysis does not include public sector (eg, military and governmental) food industries. Lastly, this analysis is likely to underestimate morbidity and mortality because of the underreporting of injury and illness rates in the BLS,<sup>42-45</sup> as well as other limitations of SOII and CFOI data.<sup>23</sup> For example, the underreporting occurs because of employer, employee, physician, and survey design factors. In addition, BLS data are not collected for farms with fewer than 11 employees and may exclude migrant or seasonal workers, which may lead to substantial undercounting. A recent interview-based study of migrant and seasonal crop workers identified an injury rate of 12.7 cases per 100 full-time employees—far in excess of our BLS data-based estimates of 4.0 injuries and illnesses per 100 full-time employees<sup>46</sup>—and a modeling analysis from 2014 estimated that approximately 75% of injuries related to agriculture may not be reported in the SOII.<sup>42</sup> There are additional limitations of the CFOI. First, it only includes traumatic causes of death and only those that occurred during a single shift or workday. Thus, it fails to capture occupational fatalities caused by long-term exposures, fatalities whose work-relatedness is difficult to establish, latent, or work-related illnesses. Work-related illnesses are associated with an estimated 49,000 deaths annually.<sup>47</sup> Therefore, it is likely that the true burden of injury and illnesses in food system industries may be higher than we have reported here.

## Implications

The increased morbidity and mortality rates for industries in all parts of the farm-to-table chain except for service suggest that considering these industries as a whole may help direct public health efforts toward this major area of American commerce. It also serves to support existing efforts to target improvements to food production worker safety, such as the National Occupational Research Agenda's National Agriculture, Forestry, and Fishing Agenda.<sup>48</sup> Furthermore, applying the farm-to-table model can serve as a heuristic for guiding consumer understanding of occupational injury, illness, and mortality as hidden costs of food production. Future work should focus on reducing disparities in occupational risks by continuing interventions to control those risks and developing new interventions when necessary. In addition, the farm-to-table model is easily communicated to consumers as well as policy makers. Future research should consider the impact on consumer purchasing practices of communicating the foodborne burden of occupational injury, illness, and mortality (ie, the burden of morbidity and mortality related to bringing food to consumers) and use the farm-to-table model to help estimate the economic impact of occupational morbidity and mortality in food system industries.

Applying the farm-to-table model is a novel construct within occupational health and has the potential to reshape the understanding of how market forces in the food industry may impact producers and consumers. The farm-to-table model unifies diverse industries into a common chain. In this way, it reshapes our understanding of the burden of "foodborne" illness to include not just pathogens and toxins that are transmitted to consumers through contaminated food, but also the costs that society bears for occupational injury, illness, and death that occur in the process of producing and delivering food to consumers.

## ACKNOWLEDGMENTS

Thank you to Dr Stephen Reynolds for his advice regarding an earlier draft of this manuscript.

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