Journal of Agromedicine

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/wagr20

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To cite this article: Rishad Ahmed, Yi Du, Gleb Haynatzki, Sarah Tucker, Athena K Ramos & Risto H Rautiainen (2024) Seasonal Patterns of Injury Characteristics Among Farmers and Ranchers in the U.S. Central States, Journal of Agromedicine, 29:4, 653-664, DOI: 10.1080/1059924X.2024.2387645

To link to this article: https://doi.org/10.1080/1059924X.2024.2387645

JOURNAL OF AGROMEDICINE
2024, VOL. 29, NO. 4, 653–664
https://doi.org/10.1080/1059924X.2024.2387645

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Seasonal Patterns of Injury Characteristics Among Farmers and Ranchers in the U.S. Central States

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ABSTRACT

Objective: In high-risk agricultural environments, tasks, weather, and work conditions vary throughout the year. Also, injuries peak during certain periods. The primary objective of this study was to examine operator- and farm-level characteristics as risk factors for injuries within each of the four seasons. The secondary objective was to examine seasonal differences in the incident location and primary cause of these injuries.

Method: We analyzed data from the 2018 and 2020 Farm and Ranch Health and Safety Surveys (FRHSS), conducted in seven U.S. states by the Central States Center for Agricultural Safety and Health (CS-CASH), which were collected using a stratified random sampling approach to ensure representativeness. The survey data were merged with operation-level data from the Farm Market iD database. We employed Generalized Estimating Equations (GEE) to examine the association of seasonal injuries with individual and operation-level characteristics. The chi-square test of independence was used to assess the association between injury incident location and season, as well as injury cause and season. Pairwise Z-tests of proportions were conducted to evaluate the differences in the proportions of injuries due to specific combinations of injury location and cause across each pair of seasons.

Results: Surveys conducted in 2018 and 2020 yielded a combined response rate of 15.9%, with 5,428 responses and 7,915 unique operators. Of these, 903 operators reported at least one injury during the past 12 months. Seasonally, most injuries occurred in spring (34.2%), followed by summer (24.7%). Male operators had higher injury odds in the spring (adjusted OR = 1.42) and summer (aOR = 2.41). Those managing both a farm and a ranch reported increased injury risks in winter (aOR = 1.73) and spring (aOR = 1.48). Operators in cow-calf operations faced higher springtime injury risks (aOR = 1.45). High stress and exhaustion were consistent risk factors across all seasons. The highest proportion of injury incidents occurred in the farmyard (43.6%), and livestock were the most common cause of injury (24.9%).

Conclusion: Results highlight the need for season-specific prevention and intervention strategies, considering farmers' and ranchers' risk characteristics, injury locations, and causes. These findings can inform targeted measures for high-risk populations at optimal times and locations.

KEYWORDS
Agricultural injury; farmers; ranchers; seasons, safety

Introduction

Agriculture is a high-risk industry, with persistently high occupational injury, illness, and fatality rates. While the nonfatal occupational injury and illness rate in agriculture, forestry, fishing and hunting industry dropped from 4.6 per 100 full-time workers in 2021 to 4.1 in 2022, it remains higher than the private industry average of 2.7 in 2022.[1] Injuries to farmers and agricultural workers are often serious. A recent study on emergency room admissions in the United States from 2015 to 2019 indicated over 60,000 individuals received treatment for nonfatal agriculture-related injuries during this period and most injuries occurred from April through September.[2] It is important to note that numerous injuries remain unreported and untreated, as highlighted by prior research.[3]

Multiple studies and reports have shown agricultural injuries peak during certain periods of the year.[4–6] Higher injury counts have been reported during the summer[7] and the fall harvest season[8]; however, injury frequency is influenced

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/1059924X.2024.2387645

by the type and intensity of tasks performed, weather, and environmental conditions. For example, during the spring, crop farmers are busy planting and preparing for the growing season. This may involve operating tractors and other heavy machinery, which can increase the risk of machine-related injuries.[9,10] Cow-calf operations, on the other hand, are typically busy during spring or fall, depending on their calving season.[10,11] During the summer months, agricultural workers may be detasseling corn, which often involves working long hours in hot and humid conditions with little time to recover.[12] This may lead to fatigue, heat exhaustion, and other health problems.[13,14] Harvest usually occurs during fall. In many parts of the Midwest, this involves running combines, tractors, and trucks, time pressure to get crops harvested, and long hours. Hence, injuries related to machinery and vehicles, as well as hazards associated with farm buildings and pastures, may be more prevalent during this particular season. During the winter, crop farmers have fewer tasks to perform, but they still do maintenance work and repairs on equipment in the farm buildings. Nevertheless, cow-calf and fed cattle producers are obligated to persist in tasks such as feeding, watering, providing shelter, monitoring, calving, and marketing their livestock. Slippery surfaces, reduced visibility, and cold weather fatigue may exacerbate the tasks. In farms and ranches, some activities and hazards overlap, while others are unique to specific types of operations. Therefore, risks are often operation-specific. Understanding seasonal variations in risk factors, injury frequency, location, and causes is crucial for effective prevention.

Despite the recognition of agriculture as being a dangerous industry and that some seasons are riskier, there remains a gap in the understanding of operator-level and farm-level characteristics as risk factors, injury locations, and causes across seasons. While previous studies have identified injury risk factors among agricultural producers,[15,16] there is limited analysis describing injury risk factors, locations, and causes by season. The availability of more accurate information on injury frequency, risk factors, primary causes, and incident locations by season would be helpful for creating more specific prevention and intervention strategies and educational resources. Also, identifying the most common combinations of injury location and cause may help in recognizing the scenarios with the highest risk to farmers and ranchers.

The current study used data from a regional seven-state surveillance program in the central U.S. conducted by the Central States Center for Agricultural Safety and Health (CS-CASH). This surveillance included both farms and ranches. The primary objective of this study was to examine operator- and farm-level characteristics as risk factors for injuries within each of the four seasons. The secondary objective was to assess whether injury location and primary cause exhibit seasonal variations.

Methods

Study site

The Farm and Ranch Health and Safety Surveys (FRHSS) were conducted in 2018 and 2020 by the Central States Center for Agricultural Safety and Health (CS-CASH) in seven U.S. states: Iowa, Kansas, Minnesota, Missouri, Nebraska, North Dakota, and South Dakota.

Surveillance methodology

The surveillance methodology used in this study was first developed as a pilot survey covering the states of Iowa and Missouri in 2008.[17] The surveys were then expanded to cover the seven-state CS-CASH region and were administered by the U.S. Department of Agriculture's (USDA) National Agricultural Statistics Service.[18] This analysis focuses on the 2018 and 2020 surveys, which the CS-CASH Surveillance Core administered to collect information on the occurrence of injuries, illnesses, and exposures among farm and ranch operators, merged with existing data on farm production characteristics from Farm Market iD (FMiD), which is currently part of DTN, a commercial subscription-based provider of information services for agriculture and other industry clients.

Data collection

Contact information for agricultural operations was purchased from FMiD. FMiD databases cover approximately 95% of the agricultural operations listed in the USDA Census of Agriculture, combining information from various sources such as government data and on-the-ground observations. In 2018, the FMiD database for seven states contained 437,042 contacts. To ensure a representative sample, a stratified random sampling approach was employed, selecting 2,500 farms per state from the FMiD database. A combination of email and mail data collection was used. The eligibility to participate in the study included the following: operations were required to be located in the seven-state region, have an email address for online surveys (applied to 2018 survey only), and have at least $5,000 USD in gross farm income. The email address was necessary to send the online surveys in 2018, while the income criteria were used to focus on active operations. Operations sampled for the 2018 survey were excluded from the 2020 sample. In 2018, two approaches were used to request responses: two emails with a link to a Research Electronic Data Capture (REDCap) online survey and two mailings to a subset of farms and ranches with a five-page questionnaire and postage-paid return envelope. UNMC REDCap is a HIPAA-compliant, secure web application for building and managing online surveys and databases. The survey covered questions about operator demographics, injuries, chronic health conditions, exposures, personal protective equipment use, and use of injury prevention techniques during the previous 12 months. Information was requested for the principal operator and up to two other operators on each farm or ranch.[19] The online survey option was dropped in 2020 due to a very low response online in 2018. The study was approved as exempt by the Institutional Review Board at the University of Nebraska Medical Center, protocol #452–11-EX.

Data merging and de-identification

The farm/ranch-level survey responses were merged with production variables from FMiD to include operation level data. A record was made for each operator to create the study dataset, and the relevant farm production variables were replicated for principal, second, and third operators who participated in the survey. The merged dataset was de-identified for analyses.[20]

Data entry and management

In 2018, the data were entered into the UNMC REDCap system either directly by operators through the online survey or by CS-CASH staff from the mail survey forms. In 2020, the survey forms were scanned and read into a Microsoft Access database using TeleForm software. Figure 1 shows the process of data collection and processing from the Farm and Ranch Health and Safety Surveys, 2018 and 2020.

Outcome variables

The survey asked farmers and ranchers about farm-related injuries they had experienced in the past 12 months. The first question focused on the frequency of injuries, asking, "How many farm-related injuries occurred to each operator during the past 12 months?", with the response options being "None", "One", "Two", or "Three or more". The second question sought to gather more specific information on the timing of the most severe injury, asking, "In what month did the most serious injury occur?", with the answer choices ranging from "Month 1" through "Month 12". Four outcome variables were created for the season in which the serious injury occurred: Fall Injury (September, October, or November), Summer Injury (June, July, or August), Spring Injury (March, April, or May), Winter Injury (December, January, or February).

Predictor variables

The predictor variables included operator-level and farm-level characteristics. At the operator level, the variables included sex (male or female), age group (11–44 years, 45–64 years, or 65+), primary operation (farming, ranching, or both), and psychological strains (dichotomized as Yes or No), indicating whether the operator experienced high

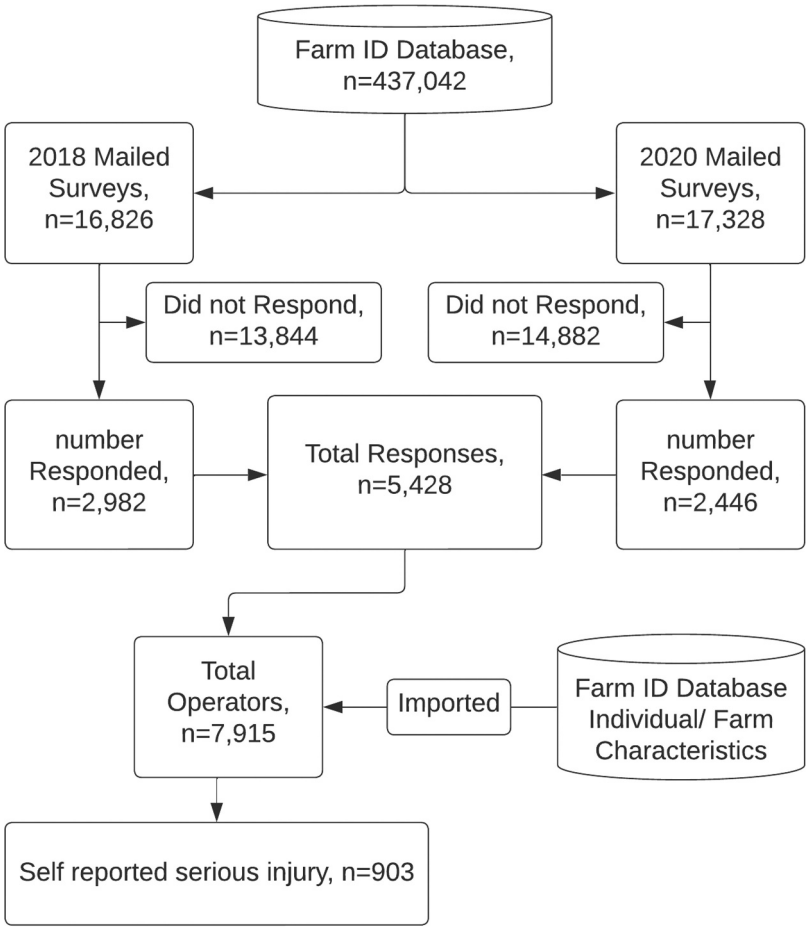

Figure 1. Flowchart of data collection and preparation.

stress, sleep deprivation, or exhaustion. At the farm level, the variables included gross farm income (<$150,000; $150,001–$350,000; or $350,000+), and production type (cow-calf, fed cattle, hay, and corn). The four production types were dichotomized (Yes or No) to indicate whether the farm produced that type of commodity.

Injury incident characteristics, such as location of injury (home/office, farm building, farm yard, field/pasture, or road/off-farm) and primary cause of injury (tractor, ATV, machinery, truck/other vehicle, power tool, hand tool, building/structure, ground/floor/surface, livestock, or other) were also analyzed to determine if their frequencies differ by season.

Statistical analysis

Statistical analyses were conducted using a combination of methods, including descriptive statistics, Generalized Estimating Equations (GEE), chi-square tests of independence, and pairwise Z-tests of proportions. Descriptive statistics were first calculated to summarize the individual and operation-level risk factor variables, stratified by seasons when the injury occurred.

The GEE approach was used for univariable analyses to examine the associations of injury and potential risk factors, separately for each injury season, and accounting for the correlated data structure (clustering of operators within farms). The models assumed a binomial distribution with a logit link function and an independent working correlation structure. Missing values in the age variable, comprising 1.5% of the data, were imputed using the mean of the observed age values. Cases with missing values in other variables were handled using listwise deletion. The final model results were reported with exponentiated coefficients (odd ratios, OR). Multivariable GEE analyses were conducted by

season where each significant variable from the univariable analyses was adjusted for age and sex, which are likely risk factors of injury.

The chi-square test of independence was used to assess the independence of injury location and season, as well as injury cause and season. The pairwise Z-test of proportions was used to assess the difference in the proportions of injuries due to a specific combination of injury location and cause between each pair of seasons. This tested whether the injuries due to a specific combination of injury location and cause was the same between each pair of seasons. SPSS software version 29 was used for all the analyses. The heatmap was generated using Python with the Seaborn package.[21]

Results

In 2018, a total of 16,826 surveys were mailed, with 2,982 responses received. In 2020, 17328 surveys were mailed out, yielding 2,446 responses. The combined response rate for the surveys was 15.89%. Across both years, there were 5,428 total responses from farm and ranch operations reporting data for 7,915 unique operators. Of the 7,915 operators, 903 reported experiencing one or more injuries. The most serious injury to each operator was included in the analyses. The majority of injuries occurred in the spring ($n = 309$, 34.2%), followed by the summer ($n = 223$, 24.7%), fall ($n = 190$, 21.0%), and winter ($n = 181$, 20.0%) (Table 1).

The univariable analyses revealed several significant associations presented in Table 1. After adjusting for age and sex (Table 2), some of these associations did not show statistical significance. Table 2 revealed the following significant season-specific and persistent risk factors across seasons.

Season-specific injury risks

After adjusting for age and sex, male operators faced higher odds of injury than female operators in both spring (OR = 1.42, 95% CI = 1.00–2.02) and summer (OR = 2.41, 95% CI = 1.41–4.11). The result for spring is borderline significant ($p = .0499$), with the lower bound of the confidence interval slightly over 1.00, which requires cautious interpretation due to rounding. Additionally, operators managing both a farm and a ranch had significantly higher odds of injury compared to those managing farm only, particularly in winter (OR = 1.73, 95% CI = 1.13–2.65) and spring (OR = 1.48, 95% CI = 1.02–2.15). Notably, operators involved in cow-calf operations also faced significantly higher injury risks during spring (OR = 1.45, 95% CI = 1.04–2.02) than operators who did not have cow-calf operations. In fall, operators with a gross farm income range of $150,000–$350,000 exhibited significantly higher injury risks compared to income range of below < 150,000 (OR = 1.67, 95% CI = 1.13–2.48).

Persistent risk factors across seasons

While some risk factors were specific to certain seasons, others persisted throughout the year. Operators who reported experiencing high stress exhibited significantly higher odds of injury compared to operators who did not experience high stress, with varying magnitudes across seasons: winter (OR = 1.49, 95% CI = 1.03–2.17), spring (OR = 1.46, 95% CI = 1.06–2.00), summer (OR = 1.49, 95% CI = 1.00–2.22), and fall (OR = 1.99, 95% CI = 1.38–2.86). The summer result is borderline significant, with the lower CI slightly over 1.00, and rounding may require cautious interpretation. Similarly, operators experiencing exhaustion showed significantly higher injury risk compared to operators who did not report exhaustion in all seasons except winter: spring (OR = 2.37, 95% CI = 1.73–3.25), summer (OR = 1.84, 95% CI = 1.29–2.62), and fall (OR = 1.46, 95% CI = 1.01–2.10).

Injury incident location and cause

Among the 903 self-reported serious injury cases, the most common incident location was the farmyard (43.6%, $n = 419$), followed by field/pasture (28.5%, $n = 274$) and farm building (19.9%, $n = 191$). The most common primary cause of injury was livestock (24.9%, $n = 243$), followed by machinery (16.7%, $n = 163$) and ground/floor/surface (11.6%, $n = 113$). The chi-square test results showed that the location of injury was not significantly associated with season (chi-square = 19.12, $p = .08$). However, the primary cause of injury was significantly associated with season (chi-square = 81.20, $p < .001$). Table 3 shows the

Table 1. Descriptive statistics and crude association of operator and farm-level characteristics with season of serious injury for the farm and ranch health and safety survey, 2018 and 2020 ($n = 7{,}915$)[a].

	Not Injured		Injured		Winter Injury			Spring Injury			Summer Injury			Fall Injury		
	n	%	n	%	n	%	OR (95% CI)[b]	n	%	OR (95% CI)[b]	n	%	OR (95% CI)[b]	n	%	OR (95% CI)[b]
Total	7012	(88.57)	903	(11.41)	181	(20.00)		309	(34.20)		223	(24.70)		190	(21.00)	
Sex																
Male	5817	(83.9)	804	(89.4)	160	(88.4)	1.46 (0.93-2.29)	271	(87.7)	1.37 (0.98-1.91)	206	(92.8)	**2.46 (1.49-4.08)**	167	(89.3)	**1.60 (1.00-2.55)[c]**
Female	1113	(16.1)	95	(10.6)	21	(11.6)	Ref	38	(12.3)	Ref	16	(7.2)	Ref	20	(10.7)	Ref
Missing	82	(1.2)	4	(0.4)	0	(0.0)		0	(0.0)		1	(0.4)		3	(1.6)	
Age groups																
11-44	1282	(18.3)	151	(16.7)	30	(16.6)	0.87 (0.56-1.35)	52	(16.8)	1.23 (0.85-1.77)	41	(18.4)	1.14 (0.77-1.68)	28	(14.7)	0.99 (0.63-1.56)
45-64	3281	(46.8)	482	(53.4)	85	(47.0)	0.96 (0.69-1.34)	176	(57.0)	**1.62 (1.24-2.13)**	113	(50.7)	1.22 (0.90-1.66)	108	(56.8)	**1.49 (1.07-2.08)**
65 and Over	2449	(34.9)	270	(29.9)	66	(36.5)	Ref	81	(26.2)	Ref	69	(30.9)	Ref	54	(28.4)	Ref
Primary operation																
Ranch	738	(11.5)	117	(13.9)	24	(14.3)	1.44 (0.92-2.25)	45	(15.8)	**1.58 (1.10-2.29)**	24	(11.5)	1.08 (0.69-1.68)	24	(13.3)	1.23 (0.79-1.91)
Both farm and ranch	649	(10.1)	134	(15.9)	31	(18.5)	**2.12 (1.40-3.21)**	46	(16.2)	**1.84 (1.28-2.65)**	34	(16.3)	**1.74 (1.18-2.57)**	23	(12.8)	1.34 (0.83-2.16)
Farm	5012	(78.3)	590	(70.2)	113	(67.3)	Ref	193	(68.0)	Ref	151	(72.2)	Ref	133	(73.9)	Ref
Missing	613	(8.7)	62	(06.9)	13	(7.2)		25	(8.1)		14	(6.3)		10	(5.3)	
Experienced high stress																
Yes	1621	(23.1)	379	(42.0)	69	(38.1)	**2.05 (1.51-2.79)**	133	(43.0)	**2.51 (1.97-3.21)**	93	(41.7)	**2.38 (1.79-3.16)**	84	(44.2)	**2.64 (1.97-3.54)**
No	5391	(76.9)	524	(58.0)	112	(61.9)	Ref	176	(57.0)	Ref	130	(58.3)	Ref	106	(55.8)	Ref
Experienced sleep deprivation																
Yes	1387	(19.8)	304	(33.7)	59	(32.6)	**1.96 (1.42-2.71)**	103	(33.3)	**2.03 (1.57-2.62)**	81	(36.3)	**2.31 (1.74-3.07)**	61	(32.1)	**1.92 (1.40-2.63)**
No	5625	(80.2)	599	(66.3)	122	(67.4)	Ref	206	(66.7)	Ref	142	(63.7)	Ref	129	(67.9)	Ref
Experienced exhaustion																
Yes	1669	(23.8)	404	(44.7)	66	(36.5)	**1.84 (1.34-2.52)**	156	(50.5)	**3.26 (2.56-4.16)**	102	(45.7)	**2.70 (2.05-3.55)**	80	(42.1)	**2.33 (1.72-3.15)**
No	5343	(76.2)	499	(55.3)	115	(63.5)	Ref	153	(49.5)	Ref	121	(54.3)	Ref	110	(57.9)	Ref
Cow calf production																
Yes	1067	(15.2)	192	(21.3)	47	(26.0)	**1.95 (1.38-2.77)**	77	(24.9)	**1.85 (1.39-2.46)**	43	(19.3)	1.33 (0.92-1.92)	25	(13.2)	0.84 (0.55-1.29)
No	5945	(84.8)	711	(78.7)	134	(74.0)	Ref	232	(75.1)	Ref	180	(80.7)	Ref	165	(86.8)	Ref
Fed cattle production																
Yes	2944	(42.0)	470	(52.0)	101	(55.8)	**1.75 (1.28-2.37)**	176	(57.0)	**1.83 (1.43-2.33)**	111	(49.8)	**1.37 (1.04-1.80)**	82	(43.2)	1.05 (0.78-1.41)
No	4068	(58.0)	433	(48.0)	80	(44.2)	Ref	133	(43.0)	Ref	112	(50.2)	Ref	108	(56.8)	Ref
Hay production																
Yes	4670	(66.6)	654	(72.4)	131	(72.4)	1.31 (0.93-1.87)	233	(75.4)	**1.54 (1.16-2.03)**	159	(71.3)	1.25 (0.93-1.68)	131	(68.9)	1.11 (0.81-1.53)
No	2342	(33.4)	249	(27.6)	50	(27.6)	Ref	76	(24.6)	Ref	64	(28.7)	Ref	59	(31.1)	Ref
Corn production																
Yes	5914	(84.3)	749	(82.9)	139	(76.8)	0.61 (0.42-0.90)	262	(84.8)	1.04 (0.74-1.45)	184	(82.5)	0.88 (0.62-1.25)	164	(86.3)	1.17 (0.77-1.78)
No	1098	(15.7)	154	(17.1)	42	(23.2)	Ref	47	(15.2)	Ref	39	(17.5)	Ref	26	(13.7)	Ref
Gross Income																
150001 -350,000	2276	(32.5)	318	(35.3)	45	(24.9)	0.85 (0.56-1.28)	83	(26.9)	1.37 (0.97-1.93)	51	(23.1)	0.87 (0.59-1.26)	69	(36.3)	**1.88 (1.27-2.78)**
350000+	605	(8.6)	79	(8.8)	74	(40.9)	0.89 (0.63- 1.25)	154	(50.0)	**1.61 (1.18-2.19)**	101	(45.7)	1.09 (0.79-1.49)	78	(41.1)	1.35 (0.91-1.98)
<150000	4120	(58.8)	503	(55.9)	62	(34.3)	Ref	71	(23.1)	Ref	69	(31.2)	Ref	43	(22.6)	Ref

[a]Participants with no injury ($n = 7{,}012$) were included in the analysis as the control group.
[b]Unadjusted Odd Ratio (OR); 95% Confidence interval (CI); bolded estimates are significant.
[c]ORs and 95% CIs are rounded to two decimal places. The exact p-value is 0.0499, indicating statistical significance at the 0.05 level. Due to rounding, the 95% CI includes 1.00.

Table 2. Multivariable analysis of the associations between operator and farm-level characteristics with season of serious injury for the farm and ranch health and safety survey, 2018 and 2020 ($n = 7{,}915$)[a].

	Winter Injury[b] OR (95% CI)[c]	Spring Injury[b] OR (95% CI)[c]	Summer Injury[b] OR (95% CI)[c]	Fall Injury[b] OR (95% CI)[c]
Sex				
Male	1.50 (0.92 - 2.43)	**1.42 (1.00 - 2.02)**[d]	**2.41 (1.41 - 4.11)**	1.53 (0.95 - 2.44)
Female	Ref	Ref	Ref	Ref
Age groups				
45-64	1.12 (0.71 - 1.77)	1.21 (0.86 - 1.70)	0.99 (0.68 - 1.45)	1.52 (0.99 - 2.33)
65 and Over	1.33 (0.83 - 2.13)	0.81 (0.56 - 1.19)	1.05 (0.69 - 1.57)	1.20 (0.75 - 1.92)
11-44	Ref	Ref	Ref	Ref
Primary operation				
Ranch	1.18 (0.74 - 1.88)	1.36 (0.92 - 2.00)	0.97 (0.60 - 1.54)	
Both farm and ranch	**1.73 (1.13 - 2.65)**	**1.48 (1.02 - 2.15)**	1.50 (0.98 - 2.30)	
Farm	Ref	Ref	Ref	
Experienced high stress				
Yes (Ref.: No)	**1.49 (1.03 - 2.17)**	**1.46 (1.06 - 2.00)**	**1.49 (1.00 - 2.22)**[d]	**1.99 (1.38 - 2.86)**
Experienced sleep deprivation				
Yes (Ref.: No)	1.31 (0.86 - 2.01)	0.90 (0.64 - 1.26)	1.21 (0.82 - 1.79)	0.96 (0.65 - 1.43)
Experienced exhaustion				
Yes (Ref.: No)	1.17 (0.79 - 1.72)	**2.37 (1.73 - 3.25)**	**1.84 (1.29 - 2.62)**	**1.46 (1.01 - 2.10)**
Cow calf production				
Yes (Ref.: No)	1.38 (0.91 - 2.09)	**1.45 (1.04 - 2.02)**		
Fed cattle production				
Yes (Ref.: No)	1.39 (0.98 - 1.99)	1.32 (0.96 - 1.80)	1.36 (0.99 - 1.86)	
Hay production				
Yes (Ref.: No)		1.23 (0.90 - 1.67)		
Gross Income				
150001 -350,000		1.18 (0.81 - 1.70)		**1.67 (1.13 - 2.48)**
350000+		1.28 (0.92 - 1.79)		1.09 (0.74 - 1.62)
<150000		Ref		Ref

[a]Participants with no injury ($n = 7{,}012$) were included in the analysis as the control group.
[b]Multivariable analysis was conducted using the generalized estimating equation (GEE) method and separately for each outcome variable (column) in the table. Age groups and sex were included as forced variables in each model, and the other predictor variables (row) that demonstrated a significant association with the outcome variable in the univariate analysis were adjusted for in the model. The adjusted odds ratios (OR) for these variables are reported in the table. The models differed in terms of number of predictor variables included for each outcome variable. For instance, the model for Winter Injury included sex, age groups, primary operation, experience of high stress, sleep deprivation, exhaustion, cow calf production, and fed cattle production, while the model for Spring Injury included sex, age groups, primary operation, experience of high stress, sleep deprivation, exhaustion, cow calf production, fed cattle production, hay production, gross income.
[c]OR = adjusted Odds ratio; CI = confidence interval. Bolded estimates are significant at the .05 significance level.
[d]ORs and 95% CIs are rounded to two decimal places. The exact p-value is 0.0499, indicating statistical significance at the 0.05 level. Due to rounding, the 95% CI includes 1.00.

frequency of the location and cause of injury incidents by season.

Pairwise comparisons were conducted to investigate the differences in the proportions of specific combinations of injury location and cause in different seasons. The results from these comparisons are summarized in Table 4. The proportion of injury from the combination of "Farm building & livestock" was significantly higher in summer and fall compared to spring. This combination also occurred more frequently in winter than in fall. The "Farmyard and other" combination was significantly more prevalent in winter than fall. "Field/pasture & machinery" was more common in fall than in winter. "Field/pasture & other" also showed a higher prevalence in fall compared to winter. While there were no other statistically significant differences in injury counts for other combinations across seasons, some combinations exhibited observable variances with higher counts in certain seasons compared to others (Figure 2).

Discussion

This is the first stratified analysis of agricultural injury risk factors, causes, and incident locations by four seasons. The identified risk factors and high-risk location-cause scenarios may provide insight into developing prevention strategies and messages for targeting high-risk injury situations at the optimal time.

Table 3. The characteristics of injury incident by season ($n = 903$).

		Injury Season											
		Winter		Spring		Summer		Fall		Total			
		n	%	n	%	n	%	n	%	n	%	Chi-square	p value
Injury location												19.12	.087
	Farm building	40	(4.4)	62	(6.9)	44	(4.9)	34	(3.8)	180	(19.9)		
	Farm yard	85	(9.4)	134	(14.8)	93	(10.3)	82	(9.1)	394	(43.6)		
	Field/pasture	34	(3.8)	97	(10.7)	64	(7.1)	63	(7.0)	258	(28.6)		
	Home/office	7	(0.8)	4	(0.4)	3	(0.3)	3	(0.3)	17	(1.9)		
	Road/off-farm	10	(1.1)	9	(1.0)	15	(1.7)	8	(0.9)	42	(4.7)		
	Missing	5	(0.6)	3	(0.3)	4	(0.4)	0	(0.0)	12	(1.3)		
	Total	**181**	**(20.0)**	**309**	**(34.2)**	**223**	**(24.7)**	**190**	**(21.0)**	**903**	**(100.0)**		
Injury cause												82.62	<.001*
	ATV	6	(0.7)	9	(1.0)	12	(1.3)	6	(0.7)	33	(3.7)		
	Building/structure	2	(0.2)	12	(1.3)	13	(1.4)	8	(0.9)	35	(3.9)		
	Ground/floor/surface	33	(3.7)	30	(3.3)	24	(2.7)	21	(2.3)	108	(12.0)		
	Hand tool	9	(1.0)	20	(2.2)	17	(1.9)	20	(2.2)	66	(7.3)		
	Livestock	54	(6.0)	104	(11.5)	45	(5.0)	23	(2.5)	226	(25.0)		
	Machinery	16	(1.8)	52	(5.8)	37	(4.1)	48	(5.3)	153	(16.9)		
	Other	34	(3.8)	36	(4.0)	34	(3.8)	30	(3.3)	134	(14.8)		
	Power tool	6	(0.7)	15	(1.7)	10	(1.1)	3	(0.3)	34	(3.8)		
	Tractor	10	(1.1)	22	(2.4)	17	(1.9)	12	(1.3)	61	(6.8)		
	Truck/other vehicle	7	(0.8)	5	(0.6)	12	(1.3)	15	(1.7)	39	(4.3)		
	Missing	4	(0.4)	4	(0.4)	2	(0.2)	4	(0.4)	14	(1.6)		
	Total	**181**	**(20.0)**	**309**	**(34.2)**	**223**	**(24.7)**	**190**	**(21.0)**	**903**	**(100.0)**		

*The Chi-square statistic is significant at the .05 level.

Table 4. Comparison of location and cause combination counts across seasons ($n = 903$).

	Injury Season				
Combination	Winter (A) n	Spring (B) n	Summer (C) n	Fall (D) n	Total
Farm yard & Livestock	24[D]	52[C D]	19	10	105
Farm yard & Machinery	9	26	20	19	74
Field/pasture & Livestock	14	33	16	8	71
Farm yard & Ground/floor/surface	18	13	13	10	54
Farm yard & Other	17[B]	11	13	11	52
Field/pasture & Machinery	1	14	8	19[A]	42
Farm building & Livestock	13	19	5	5	42
Field/pasture & Other	2	15	10	13[A]	40
Farm yard & Hand tool	4	9	7	12	32
Farm building & Machinery	5	10	7	8	30
Field/pasture & Ground/floor/surface	9	10	5	5	29
Farm yard & Tractor	5	7	8	8	28
Farm building & Other	8	4	8	3	23
Field/pasture & Tractor	1	9	9		22
Field/pasture & ATV	4	6	7		22
Farm building & Power tool	3	8	8		19
Farm building & Building/structure	1	8	5		19
Field/pasture & Hand tool	1	8	4		17
Farm building & Ground/floor/surface	4	5	3		17
Road/off-farm & Truck/other vehicle	2	3	5		14
Farm yard & Truck/other vehicle	5	2	2		14
Farm building & Hand tool	2	3	5		14
Farm yard & Building/structure	0[1]	4	6		13
Farm yard & Power tool	2	5	2		11
Other combinations (cases =<10)	18	18	22		73
Missing	9	7	6		26
Total	**181**	**309**	**223**		**903**

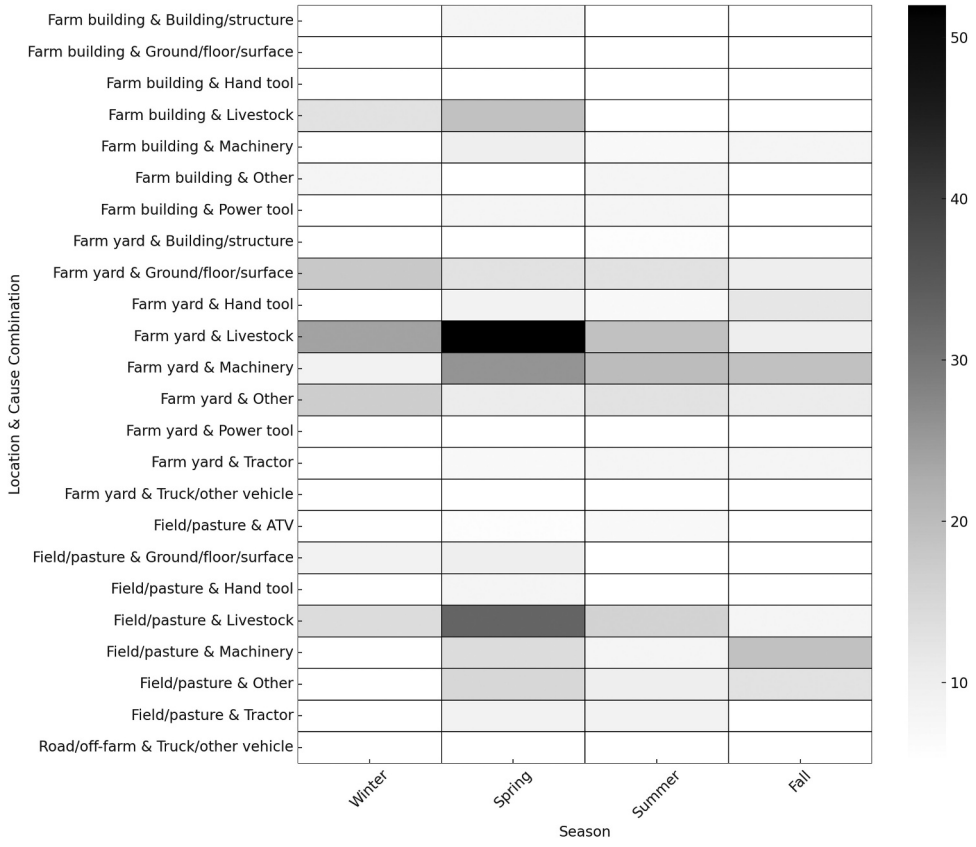

Figure 2. Heatmap of season vs. Location and cause combinations.

The heatmap illustrates the frequency of injuries across four seasons and specific combinations of injury locations and causes. The legend on the right shows the frequency scale, with lighter shades representing fewer injuries and darker shades representing more injuries.

The adjusted odds of injury were higher for operators managing both crop farms and ranches compared to operators who manage farms alone in winter and spring. These operators are exposed to a wider range of hazards related to both crop production (such as machinery, chemicals, and repetitive motion during the busy planting season) and those associated with livestock handling (such as bites, kicks, slips and falls during the busy calving season).[22–24] The heavy workload of managing crops and animals year-round can be compounded by seasonal hazards like snow and icy conditions and the inherently risky nature of calving season, with its long hours and physically demanding tasks.

Fatigue, stress, and exhaustion are common conditions among agricultural workers and they are associated with an increased risk of injuries.[25,26] The odds of injury for operators who experienced high stress and exhaustion were higher in all seasons in the current study. Pain, self-rated health, animal handling, decision latitude, and job demands have been associated with physical and mental fatigue among workers in cattle feeding operations in a previous study.[25]

One out of nine injuries in the current study were caused by livestock in the spring season; with cow-calf operations being significant contributors. Cattle-related injuries also peaked during the calving season in a New Zealand study.[27] Spring is the predominant calving season in U.S. agriculture, typically around March-April.[28] Increased protective behavior of mother cows towards their newborn calves is a major injury risk.[29] Mother cows can exhibit aggressive behaviors, such as kicking or pinning workers to protect their calves,[30,31] while workers are involved in tasks such as assisting with the birthing process, providing care to the newborn calves, or handling the mother cows. Calving season is a physically demanding time that can be quite exhausting due to the long hours and demanding

nature of the tasks involved. In our data, operators who reported exhaustion had a 2.37 times higher risk of injury compared to those who did not report exhaustion during the spring. Training in safe handling of animals and fatigue management may improve safety of the operators during spring calving season.

Combinations of injury location and cause varied by season in pairwise comparisons. For instance, injuries involving "Farm yard & livestock" were more frequent in the spring compared to summer and fall (Table 4 and Figure 2). This underscores the potential for considering injury location and cause-specific interventions tailored to each season.

The findings of this study emphasize opportunities to target interventions to producers and workers by considering optimal times of the year to address specific risk factors, injury locations, and causes. Timing of farm safety messages should prioritize the most common causes of injuries in each season, including preparedness and preventive maintenance during the off-season to reduce the risk of hazardous breakdowns and stressful interruptions during peak seasons. Efforts such as the annual farm safety and health week each September can effectively remind farmers and the general public about hazards during harvest time, including the dangers of farm machinery on public roads.

Combining season-specific insights with operation-specific risk factors may enhance the effectiveness of injury prevention strategies. Implementing season-specific messages could involve distributing targeted safety reminders, conducting training sessions, and providing safety checklists at the beginning of each season. Additionally, safety strategies may need to be customized based on the type of operation and the prevalence of specific hazards in the work environment.

Limitations

The FRHSS had a low response rate, which can impact the generalizability of the findings. However, a previous study found little evidence of nonresponse bias in this dataset based on comparison of respondent and non-respondent characteristics.[32] The diversity of geography, climate, crops grown, and animals raised in the seven-state region introduces variability in peak activity periods. Different farms may have unique "rush" seasons due to special situations, such as animal health or weather-related events. Therefore, specific local and regional situations should be considered in seasonally targeted intervention strategies. In this study, the included states represent the Midwest and Great Plains, so results may not be generalizable to other U.S. regions, where agricultural practices can differ significantly. Moreover, reliance on self-reporting of injuries may affect the distribution of injuries reported during the seasons. The surveys were administered during the late spring and summer, and it is likely that respondents remember the most recent injuries (spring, summer) better than those that happened many months ago (winter, fall). This potential bias (under-reporting) may be particularly pronounced for injuries that occurred in the fall. To mitigate this limitation, future iterations of the survey will be distributed at the end of the fall season, aiming to reduce the recall bias associated with the season of data collection.

Conclusion

This study examined seasonal variation in injury risk factors and patterns among farmers and ranchers in the U.S. Central States. Our findings suggest that season-specific prevention and intervention measures are needed to address the unique risks faced by farmers and ranchers at different times of the year.

Acknowledgments

Kaeli Samson prepared datasets for analyses.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was supported by the CDC/NIOSH through the Co-operative Agreement U54 OH010162 to the Central States Center for Agricultural Safety and Health (CS-CASH).

Institution and ethics approval and informed consent

University of Nebraska Medical Center Institutional Review Board approved this study protocol as exempt (#452–11-EX).

Authors' contributions

Rishad Ahmed participated in the research methodology design and data analysis/interpretation and drafted and finalized the manuscript. Risto H Rautiainen was the Principal Investigator responsible for the research methodology design, data collection, and the draft's critical evaluation. Yi Du participated in the design of the research methodology, data analysis, and critical evaluation of the draft. Sarah Tucker participated in critically evaluating the draft. Athena K Ramos participated in critically evaluating the draft. Gleb Haynatzki participated in the research methodology design and critically evaluated the draft.

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