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Dermal Exposure to Agrochemicals as Risk Factor for Skin Cancer in Farmers and Ranchers in the US Central States

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ABSTRACT

Background: Farm operators are at a high risk of developing skin cancer due to their occupational sun exposure. With the growing incidence of skin cancer, it is also important to evaluate other occupational risk factors. Farm operators confront numerous physical, chemical, and biological hazards in their work environment. This study investigated whether dermal exposures to pesticides/fertilizers, animals/livestock, detergents/disinfectants, and fuels/solvents/paints were associated with the risk of skin cancer in farm and ranch operators.

Methods: Surveillance data from the Central States Center for Agricultural Safety and Health (CS-CASH) Farm and Ranch Health and Safety Surveys in 2018 and 2020 were used to explore the risk of skin cancer in farm operators in seven US central states. Farm production variables from the DTN Farm Market database were merged with survey responses. The associations of skin cancer and exposure variables were analyzed using descriptive statistics and regression modeling.

Results: The prevalence of skin cancer was 10% among 7943 operators. Univariable analyses showed that men had 1.62 times higher odds of skin cancer compared to women. The odds of skin cancer increased significantly with age. Livestock, fed cattle, cow-calf, and beef production increased the odds of skin cancer. Exposure to pesticides/fertilizers and fuels/solvents/paints also increased the odds of skin cancer compared to unexposed operators. In the final multivariable model, the associations of skin exposure to pesticides/fertilizers (odds ratio (OR) = 1.30, 95% CI: 1.08–1.56) and to fuels/solvents/paints (OR = 1.21, 95% CI: 1.01–1.45) remained statistically significant after adjusting for sex, age, and state. Having livestock also increased the odds of skin cancer (OR = 1.18, 95% CI: 1.00–1.38).

Conclusion: Skin is a critical source of occupational exposures among farm operators. Increased odds of skin cancer in this study emphasizes the need for better protection against exposures to chemicals including pesticides/fertilizers, and fuels/solvents/paints.

This study was presented at the University of Nebraska Medical Center.

1 | Introduction

Skin cancer is among the most diagnosed forms of cancer in the United States and globally [1]. During the period of 2016–2018 in the United States, the proportions of individuals aged 65 and older who received treatment for all types of skin cancer were 9.5% for men and 6.7% for women, respectively [2]. The prevalence of non-melanoma skin cancer (NMSC) was higher (8.2% males and 6.1% females) compared to melanoma (1.5% males and 0.7% females) during those years. The incidence of NMSC has been rising over the past two decades in the United States and Europe [2, 3]. The incidence of melanoma, the most lethal form of skin cancer, has also increased globally, particularly, in developed countries where contributing factors include ultraviolet radiation (UVR) exposure, indoor tanning, immune suppression, obesity, moles, diagnostic testing, and occupational exposure to tar, mineral oils, and infrared radiation [4, 5].

The incidence of skin cancer varies by occupation, and farm operators are at a higher risk due to sun exposure during frequent outdoor work, in contrast to individuals who are not occupationally exposed to the sun [6]. Male agricultural workers have been found to exhibit higher melanoma rates compared to females in the general population [7]. Many studies have examined potential reasons for the high skin cancer incidence among agricultural workers, including their attitudes and behaviors toward protecting their skin from UVR exposure [8]. However, additional occupational risk factors apart from UVR could contribute while their role is not well understood in this population [9, 10]. Agrochemical exposures have been implicated as potential factors in the development of skin cancer [11–14]. An Australian study reported higher exposures to carcinogens in mixed livestock and crop farms compared to those engaged in crops-only farming [15]. Farmers are also exposed to fuels, solvents, and paints, particularly during machinery repair and maintenance activities [16]. Paints often contain organic solvents such as xylene, toluene, styrene, perchloroethylene, acetone, and methylethylketone [17]. These organic solvents can induce DNA damage in human skin through indirect mechanisms, such as oxidative stress [17], potentially leading to cancer.

The limited and, in some cases, conflicting information from previous studies highlights the need for evaluating potential occupational risk factors for skin cancer beyond UVR exposure. Identifying major risk factors is important to the prevention of skin cancer, particularly to those factors that could be more controllable than sun exposure in challenging outdoor working conditions. The surveillance surveys conducted by the Central States Center for Agricultural Safety and Health (CS-CASH) provided a unique opportunity to investigate occupational risk factors for skin cancer among agricultural producers. The main objective of this study was to explore whether self-reported dermal exposures to pesticides/fertilizers, animals/livestock, detergents/disinfectants, and fuels/solvents/paints were associated with the risk of skin cancer diagnosed by a physician in farm and ranch operators located in the US central states.

2 | Methods

2.1 | Study Site

Since 2011, CS-CASH has been collecting surveillance data on agricultural injury and illness in seven US states: Iowa (IA), Kansas (KS), Minnesota (MN), Missouri (MO), Nebraska (NE), North Dakota (ND), and South Dakota (SD) [18]. The surveillance methodology was developed by the CS-CASH research team, focusing on injuries during the first 5 years. In 2018 the surveys were updated with additional questions on chronic health conditions, including skin diseases, which were not addressed in the prior survey years. The University of Nebraska Medical Center Institutional Review Board approved this study protocol as exempt (#452-11-EX).

2.2 | Data Collection

This study used data from CS-CASH Farm and Ranch Health and Safety Surveys (FRHSS), which captured responses from self-employed farmers and ranchers referred to as "operators." Farms and ranches (operations) were randomly selected for the surveys from the databases of Farm Market iD (FMiD), a private agricultural information services company, currently known as DTN Farm Market Data, which has data on more than 95% of US farm operations [19]. According to the 2017 Census for Agriculture, there were approximately 2 million farms in the United States, with about 411,000 (21%) of them in the study region [20]. A stratified random sampling approach was employed, requesting 2500 farms per state from DTN in both 2018 and 2020. Farms with less than $5000 estimated gross farm income were excluded from the sample. Additionally, for the 2018 survey, farms were required to have an email address, and all those selected for the 2018 survey were excluded from the 2020 survey population. The study's geographical scope was limited to farms and ranches located in the seven-state region. The questions about skin disease outcomes and exposures were the same in the 2018 and 2020 surveys.

From the 2018 survey, after the cleansing of addresses, a total of 16,826 farm operations were included in the mailings, while for the 2020 survey, this number increased to 17,328 (Figure 1). The survey questions contained information about operator demographics, acute injuries, information on youths and other family members involved in farm operations, hired workers, chronic health conditions, and exposures to operators within the past 12 months. For a comprehensive view, respondents were asked to provide this information for up to three individuals: principal operator, second operator, and third operator of each farm operation. The full survey can be found in the supplementary materials [21]. To enhance the depth of analysis, production variables from DTN data were merged with the FRHSS responses, resulting in a data set at the operation level. Subsequently, a final research data set was created at the individual operator level by merging the survey data for each operator with corresponding DTN farm variables pertaining to their operation.

2.2.1 | Dependent Variable

Skin conditions were assessed using the following survey question: "Has the operator ever been diagnosed by a physician

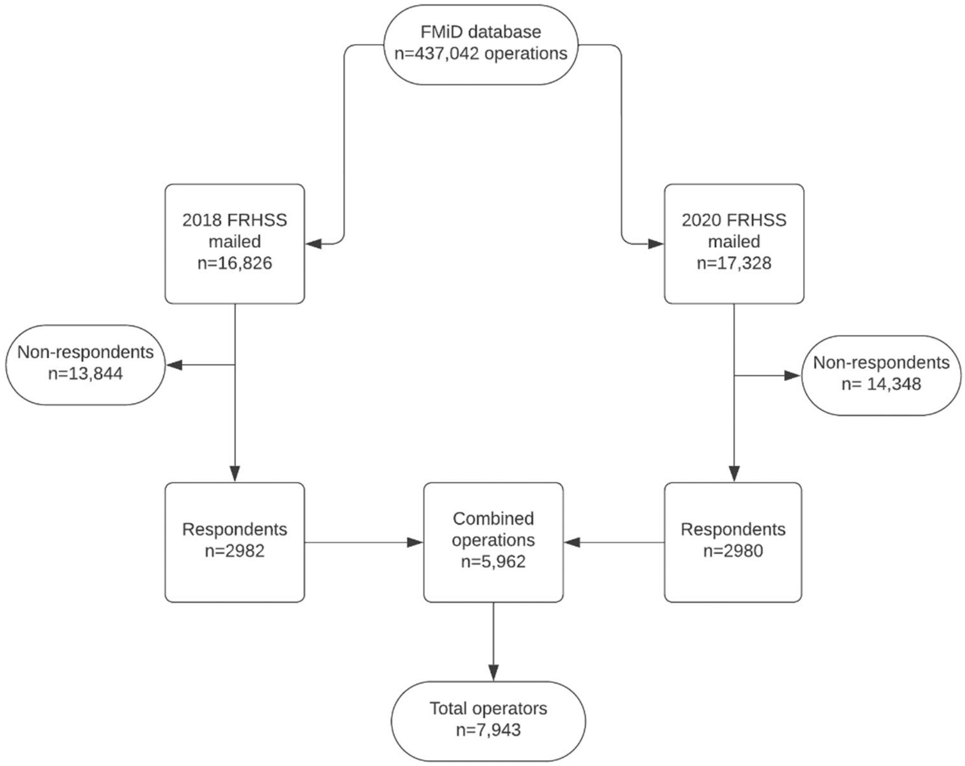

FIGURE 1 | Flowchart showing the selection process for the data set for analysis from Farm Ranch Health and Safety Surveys 2018 and 2020 combined.

with any of the following skin conditions? (Mark all that apply.)" Response options included "None, Irritant dermatitis, Allergic dermatitis, Skin cancer, and Other, Specify (free response)." For our analyses, we dichotomized the outcome variable into "Yes" and "No" categories for skin cancer. Specifically, respondents were categorized as "Yes" if they indicated having skin cancer and did *not* report any other skin disease. Other skin conditions were not included in this outcome because it would be difficult to determine and interpret the relationship between the exposure and outcome if the outcome variable included skin diseases other than cancer.

2.2.2 | Independent Variables

The primary variables of interest, pertaining specifically to skin exposures, were identified with the following survey question: "Was the operator exposed to any of the following chemicals or animal-based allergens while working during the past 12 months? (Mark all that apply.)" Response options were "None, pesticides/fertilizers, animals/livestock, detergents/disinfectants, fuels/solvents/paints, and other, specify (free response)." Additional potential predictor variables at the operator level were examined, including operator sex (male or female), age (age groups: 0–< 50, 50–< 65, 65–< 101), operation type (farm, ranch, or both), primary occupation (farm/ranch work or other type of work), and percentage of work time spent on farm/ranch work (categorized as 0%–24%, 25%–49%, 50%–74%, 75%–99%, and 100%), and state (listed under Study Site) as an indicator for differences in agricultural practices and sun exposure due to latitude. These variables were also considered for predictor variables in multivariable regression modeling. Furthermore, production-level variables were incorporated, including various crops and animals raised, such as corn, hay, wheat, beef, dairy, cereal grains, livestock, pasture/rangeland, legumes, corn & soy, soybeans, cow-calf, and fed cattle. All the production-level variables were dichotomized, classifying the presence or absence of any quantity of the reported products (Yes/No).

2.2.3 | Data Analysis

Descriptive analyses were conducted using cross-tabulation to explore the relationship between the outcome variable, skin cancer diagnosis, and the selected operator-level and production-level exposure variables. Descriptive statistics, along with χ^2 test results, were reported to provide a preliminary overview. Predictor variables showing a significant association with skin cancer in the unadjusted analyses were chosen for inclusion in the regression modeling. Univariable Generalized Estimating Equations (GEE) regression analyses were performed to assess the relationship between the primary outcome and each of the selected exposure variables. Exposure variables demonstrating a significant association in the univariable models were included in the subsequent multivariable regression phase with a *p*-value of 0.15 as a threshold for initial inclusion. For the construction of the multivariable models, backward selection was used, with age, sex, and state being forced into each model. Both unadjusted (crude) and adjusted odds ratios (ORs) were reported to quantify the association between the exposure variables and skin cancer outcome. The final adjusted model included the following variables: sex, age, state, skin exposure to pesticide/fertilizer, skin exposure to fuels/solvents/paints, and livestock. All statistical analyses were conducted using SAS 9.4 (SAS Institute Inc, Cary, NC, USA).

3 | Results

The 2018 and 2020 combined FRHSS response rate was 16%. The final data set consisted of 5962 operations and 7943 operators, of whom 6621 were males (83%), 1208 were females (16%), and 1% had a missing response. The median age of the operators was 60 years old. Skin cancer was reported by 10% of the operators. Demographic results are presented in Table 1. Of skin cancers, 716 cases (89%) were reported by males, while 84 cases were reported by females (10%). High frequencies of skin cancer were observed in the oldest age group (65–100 years) with 527 cases (65%), and among operators spending most of their time working on the farm (50% or more), with 653 cases (81%). Similarly, higher frequencies of skin cancer were found

TABLE 1 | Demographic and occupational characteristics by skin cancer among operators ($n = 7943$).

	Skin cancer			
Operator characteristics	**Yes, *n* (%)**	**No, *n* (%)**	**χ^2 *p*-value**	**OR (95% CI)**
Total	809 (10.2)	7134 (89.8)		
Sex				
Male	716 (88.6)	5905 (82.8)	< 0.01	1.62 (1.28–2.05)*
Female	84 (10.4)	1124 (15.8)		Reference
Missing	9 (1.00)	105 (1.40)		
Age group				
65–< 101	527 (65.1)	2192 (30.7)	< 0.01	17.39 (11.59–26.09)*
50–< 65	251 (31.0)	3047 (42.7)		5.96 (3.93–9.02)*
0–< 50	25 (3.15)	1808 (25.3)		Reference
Missing	6 (0.75)	87 (1.30)		
Percent work time				
100%	394 (48.7)	3265 (45.8)	< 0.01	1.29 (0.98–1.71)
75%–99%	164 (20.3)	1266 (17.8)		1.39 (1.03–1.89)*
50%–74%	95 (11.7)	803 (11.3)		1.27 (0.91–1.77)
25%–49%	88 (10.9)	964 (13.5)		0.98 (0.70–1.37)
0%–24%	63 (7.79)	676 (9.48)		Reference
Missing	5 (0.61)	160 (2.12)		
Primary occupation				
Farm/Ranch work	663 (82.0)	5369 (75.3)	< 0.01	1.41 (1.17–1.71)*
Other	140 (17.3)	1597 (22.4)		Reference
Missing	6 (0.70)	168 (2.3)		
Type of operation				
Farm	574 (71.0)	5028 (70.5)	0.86	1.08 (0.84–1.39)
Ranch	84 (10.4)	771 (10.8)		1.03 (0.74–1.43)
Both	75 (9.27)	708 (9.92)		Reference
Missing	76 (9.33)	627 (8.78)		
State				
MO	115 (14.2)	642 (9.0)	< 0.01	2.56 (1.84–3.55)*
IA	161 (19.9)	1178 (16.5)	< 0.01	1.95 (1.43–2.66)*
KS	104 (12.9)	804 (11.3)	< 0.01	1.84 (1.32–2.57)*
NE	182 (22.5)	1584 (22.2)	< 0.01	1.64 (1.21–2.22)*
SD	108 (13.3)	1017 (14.3)	< 0.01	1.51 (1.09–2.10)*
MN	77 (9.52)	1006 (14.1)	0.63	1.09 (0.77–1.53)
ND	60 (7.43)	855 (11.9)		Reference
Missing	2 (0.25)	48 (0.70)		

*Statistically significant at $p < 0.05$.

among operators whose primary occupation was farm/ranch work, accounting for 663 cases (82%). The frequencies of skin cancer differed by state with the lowest found in ND and the highest found in MO. The frequency of skin cancer was comparable for those operating different types of farms. Higher frequencies of skin cancer were observed among those who reported beef ($n = 413$, 51%) and livestock ($n = 421$, 52%) production. However, the frequencies were lower for those reporting having cow-calf (156 cases, 19%), and fed cattle production (398 cases, 49%). The results are presented in Table 2. Furthermore, higher frequencies of skin cancer were found in individuals reporting skin exposure to pesticides/fertilizers (483 cases, 60%) and fuels/solvents/paints (461 cases, 57%) (Table 3).

The unadjusted univariable analyses in Table 1 show that men had 1.62 times higher odds of skin cancer compared to women. The odds of skin cancer significantly increased with age, with the highest age group demonstrating 17.4 times the odds of skin cancer compared to the lowest age group. Those individuals whose primary occupation was farm/ranch work had 1.41 times the odds of skin cancer compared to those who reported other work as their primary occupation. However, the percentage of working time on the farm/ranch and type of operation were not significantly associated with cancers. Those who lived in MO and IA had 2.56 and 1.95 times the odds of skin cancer, respectively, compared to those who lived in ND. Those who lived in KS and NE had 1.84 and 1.64 times the odds of skin cancer, respectively, compared to those who lived in ND. The univariable analysis in Table 2 indicates that fed cattle, cow-calf, livestock, and beef production were associated with higher odds of skin cancer (ORs 1.33, 1.31, 1.31, and 1.31, respectively). However, the other production-level variables were not significant. In Table 3, operators with skin exposure to pesticides/fertilizers had higher odds of skin cancer (OR = 1.27, 95% CI: 1.10–1.48) compared to operators with no skin exposure to pesticides/fertilizers. Similarly, operators with skin exposure to fuels/solvents/paints had higher odds of skin cancer (OR = 1.22, 95% CI: 1.05–1.41) compared to operators with no skin exposure to fuels/solvents/paints. However, skin exposure to animals/livestock and skin exposure to detergents/disinfectants were not significantly associated with skin cancer.

The final model of the multivariable analysis included sex, age, state, skin exposure to pesticides/fertilizers, skin exposure to fuels/solvents/paints, and the presence of any livestock presented in Table 4. After adjusting for sex, age, and state, the multivariable analysis revealed that individuals with skin exposure to pesticide/fertilizer had 1.30 times the odds of skin cancer (95% CI: 1.08–1.56) compared to those without such exposure. Similarly, individuals with skin exposure to fuels/solvents/paints exposure had 1.21 times the odds of skin cancer (95% CI: 1.01–1.45) compared to those without such exposure. Moreover, having any livestock was also significantly associated with higher odds of skin cancer (OR = 1.18, 95% CI: 1.00–1.38).

4 | Discussion

Our study underscores the significance of skin exposures as potential risk factors for skin cancer among farm operators. The odds of skin cancer were 1.27 times higher in individuals with skin exposure to pesticides/fertilizers compared to those unexposed, and 1.22 times higher in individuals with skin exposure to fuels/solvents/paints compared to those unexposed. These associations remained significant even after controlling for age, sex, and state in the multivariable model. Specifically, pesticide/fertilizer exposure increased in effect size as a risk factor for skin cancer (OR = 1.30). Although the effect size of fuels/solvents/paints skin exposure as a risk factor slightly decreased in the multivariable model (OR = 1.21), it remained borderline significant ($p = 0.046$). The finding of pesticide/fertilizer exposure as a risk factor for skin cancer aligns with the results of a case–control study within the US Agricultural Health Study cohort, which found a significant association between exposure to three pesticides and melanoma skin cancer (OR = 2.4, 95% CI, 1.2–4.9 for maneb/mancozeb; OR = 2.4, 95% CI, 1.3–4.44 for parathion; OR = 1.7, 95% CI, 1.1–2.5 for carbaryl) in pesticide applicators compared to the controls [12]. Similarly, the Great Britain Pesticide Users Health Study (PUHS) reported a statistically significant excess for incidence of NMSC among male and female agricultural pesticide users [13]. An Italian hospital-based case–control study on cutaneous melanoma and residential pesticide use reported subjects exposed ≥ 4 times annually to indoor pesticides had 2.2 times the risk of melanoma compared to those ≤ 1-time annual exposure (95% CI: 1.07–4.43) [22]. The study controlled for sun exposure-related variables, phenotype traits, and number of common nevi. A pooled analysis of two case–control studies involving occupational groups from two regions of the world examined the association between exposure to pesticides and cutaneous melanoma [23]. The authors reported higher odds of melanoma with exposure to any pesticide compared to no exposure (OR = 2.58, 95% CI: 1.18–5.65), even after controlling for confounders which included sun exposure-related variables [23]. Moreover, the use of pesticides for 10 years or more was significantly associated with melanoma, and the use of herbicides (OR = 3.08, 95% CI: 1.06–8.97) and fungicides (OR = 3.88, 95% CI: 1.17–12.9) were significantly associated with melanoma after controlling for confounding variables [23]. Additionally, an interactive effect was observed between exposure to pesticides and occupational sun exposure, with subjects exposed to both having a greater risk of melanoma compared to subjects without occupational sun exposure (OR = 4.68, 95% CI: 1.29–17.0), even after controlling for confounding variables [23]. A study by Watanabe-Galloway et el. found that less than half of agricultural producers in Nebraska were currently up to date with skin cancer screening (46%) [24]. Furthermore, they reported age, income, and family history of cancer were significantly associated with current skin cancer screening [24]. It is important to note the disparities in age and income as areas of improvement in cancer screening among agriculture producers in Nebraska. Regular screening is important especially for outdoor workers like farmers [9]. Based on the study by Watanabe-Galloway et al. and the results from our study, more opportunities for skin cancer screening should be deployed throughout the state of Nebraska, specifically targeting agricultural workers. Free screening could be provided at the community level, as well as at various agricultural events that agricultural producers attend. [Correction added on 8 January 2025, after first online publication: Reference citations at the end of two sentences---"An Italian hospital-based case..." and "Moreover, the use of pesticides..."---have been updated to [22] and [23], respectively, in this version.]

Despite the growing evidence, the association of pesticide exposure and skin cancer risk remains unclear. An updated

TABLE 2 | Farm product characteristics by skin cancer among operators ($n = 7943$).

	Skin cancer			
Production	**Yes, *n* (%)**	**No, *n* (%)**	**χ^2 *p*-value**	**Odds ratio (CI)**
Total	809 (10.2)	7134 (89.8)		
Corn				
Yes	661 (81.7)	5989 (84.0)	0.10	0.85 (0.71–1.03)
No	148 (18.3)	1145 (16.0)		
Hay				
Yes	536 (66.3)	4772 (66.9)	0.72	0.97 (0.83–1.13)
No	273 (33.7)	2362 (33.1)		
Wheat				
Yes	265 (32.8)	2577 (36.1)	0.06	0.86 (0.73–1.01)
No	544 (67.2)	4557 (63.9)		
Beef				
Yes	413 (51.0)	3160 (44.3)	< 0.01	1.31 (1.13–1.52)*
No	396 (49.0)	3974 (55.7)		
Dairy				
Yes	38 (4.7)	379 (5.30)	0.46	0.87 (0.62–1.24)
No	771 (95.3)	6755 (94.7)		
Cereal grains				
Yes	703 (86.9)	6379 (89.4)	0.03	0.79 (0.63–0.98)
No	106 (13.1)	755 (10.6)		
Livestock				
Yes	421 (52.0)	3231 (45.3)	< 0.01	1.31 (1.13–1.52)*
No	388 (48.0)	3903 (54.7)		
Pasture/rangeland				
Yes	763 (94.3)	6812 (95.5)	0.13	0.78 (0.57–1.01)
No	46 (5.70)	322 (4.50)		
Legumes				
Yes	641 (79.2)	5867 (82.2)	0.03	0.82 (0.69–0.99)
No	168 (20.8)	1267 (17.8)		
Corn and soy				
Yes	705 (87.1)	6377 (89.4)	0.05	0.80 (0.64–1.01)
No	104 (12.9)	757 (10.6)		
Soybeans				
Yes	632 (78.1)	5772 (80.9)	0.06	0.84 (0.71–1.01)
No	177 (21.9)	1362 (19.1)		
Cow-calf				
Yes	156 (19.3)	1101 (15.4)	< 0.01	1.31 (1.09–1.58)*
No	653 (80.7)	6033 (84.6)		
Fed cattle				
Yes	398 (49.2)	3009 (42.2)	< 0.01	1.33 (1.15–1.54)*
No	411 (50.8)	4125 (57.8)		

*Statistically significant at $p < 0.05$.

TABLE 3 | Skin exposure factors by skin cancer among operators ($n = 7943$).

Skin exposure factors	Skin cancer No, *n* (%)	Skin cancer Yes, *n* (%)	χ^2 *p*-value	Odds ratio (CI)
Total	7134 (89.8)	809 (10.2)		
Pesticides/fertilizers				
Yes	3833 (53.7)	483 (59.7)	0.00	1.27 (1.10–1.48)*
No	3301 (46.3)	326 (40.3)		
Animals/livestock				
Yes	2747 (38.5)	294 (36.3)	0.23	0.91 (0.78–1.06)
No	4387 (61.5)	515 (63.7)		
Detergents/disinfectants				
Yes	1584 (22.2)	176 (21.8)	0.77	0.97 (0.81–1.16)
No	5550 (77.8)	633 (78.2)		
Fuels/solvents/paints				
Yes	3721 (52.2)	461 (57.0)	< 0.01	1.22 (1.05–1.41)*
No	3413 (47.8)	348 (43.0)		
Other				
Yes	68 (0.90)	11 (1.40)	0.27	1.43 (0.75–2.72)
No	7066 (99.1)	798 (98.6)		

*Statistically significant at $p < 0.05$.

TABLE 4 | Multivariable analysis of risk factors associated with skin cancer.

Risk factors	OR	95% CI
Pesticides/fertilizers (yes vs. no)	1.30*	1.08–1.56
Fuels/solvents/paints (yes vs. no)	1.21*	1.01–1.45
State		
IA	1.84*	1.34–2.54
KS	1.69*	1.20–2.39
MN	1.03	0.72–1.47
MO	2.07*	1.46–2.92
NE	1.56*	1.41–2.14
SD	1.51*	1.08–2.13
ND	Ref	
Sex (male vs. female)	1.44*	1.11–1.84
Age group		
65–< 101	17.8*	11.8–26.7
50–< 65	6.08*	4.01–9.23
0–< 50	Ref	
Livestock (yes vs. no)	1.18*	1.00–1.38

*Statistically significant at $p < 0.05$.

Agriculture Health Study in 2010 reported no excess risk of melanoma in pesticide applicators but did find an excess of melanoma in applicator spouses (relative standardized incidence ratio = 1.64, 95% CI: 1.33–2.02) [25]. However, the authors did not elaborate on other agricultural exposures that might explain the association. A systematic review and meta-analysis reported that ever-exposure to herbicides was associated with an increased risk of cutaneous melanoma (summary relative risk = 1.85, 95% CI: 1.01–3.36), but no increased risk was associated with exposure to insecticides or exposure to any pesticide [26].

Farmers are often exposed to fuels, oils, and solvents when working with maintenance/repair of tractors and other farm machinery [16, 27]. Identifying these types of chemical exposures and their association with skin disease outcomes in farmers is challenging due to underreporting or non-reporting [16]. A pilot study quantifying dermal exposure to organic solvents in farmers reported elevated levels of toluene (9 out of 10 participants) and xylene (all 10 participants) [27]. Additionally, exposure to mineral oil has been shown to increase the risk of melanoma in a cohort of aerospace workers [28]. This is an understudied area and requires further attention to better protect farmers from fuels, oils, and solvent exposure especially with co-exposure to other occupational hazards.

A noteworthy and interesting finding in this study was that having any livestock production was a risk factor for skin cancer. A European exploratory study investigating occupation and risk of NMSC reported a significant association between livestock work and squamous cell carcinoma (OR = 2.11, 95% CI: 1.11–4.03) after controlling for sun exposure [29]. Even though our study did not control for sun exposure, other factors might explain the increased odds of skin cancer in livestock producers. Livestock producers encounter various potential hazardous environmental and occupational exposures, including pharmaceuticals, antibiotics, hormones, endotoxins, zoonotic diseases, and pesticides. It has also been reported that mixed livestock and crop farmers experience higher average exposure to carcinogens than those engaged in crop-only or livestock only farming [15]. Livestock production is common in the US central states [30], making it crucial to explore other possible occupational risk factors for chronic diseases in livestock producers. Notably, in the multivariable model, primary occupation was no longer significant. Primary occupation of farm/ranch work might not be a predictor for skin cancer; instead, specific production variables, such as livestock production, were found to be more important. Farmers may have off-farm occupations that expose them to carcinogens. This could also explain why primary occupation was not a significant predictor for skin cancer. Farm/ranch occupation did not explain the specific potential types of exposures; instead, the type of work or production that operators were involved in might better explain exposures to specific chemical, biological, or physical agents related to skin cancer.

Strengths of this study lie in its large sample size, which represents an agriculture population of farm operators in the US central states. Additionally, the use of combined data from two survey years enhanced the robustness of the analysis. Furthermore, nonresponse bias was not identified as a significant issue in this surveillance research [31]. Very few differences were found between responders and nonresponders in the 2018 CS-CASH survey. Responders to first mailing reported more injuries and greater severity compared to late responders to reminder mailing. Overall, the differences identified between responders and nonresponders were minimal and unlikely to create bias [31]. The skin cancer incidence in this study (10%) was within the range of skin cancer incidence in agricultural populations from other studies in California (5%), and Ohio (20%) [32, 33]. Although direct sun exposure measures were not included in the survey, the state the participants lived in was considered an indicator for latitude. There was a significant effect found between the northernmost and southernmost states, which aligns with other research showing latitude as a risk factor for skin cancer [34]. The survey design aimed to minimize direct linking of outcome and exposure questions that could have a strong causal association, thus reducing potential bias. However, other limitations need to be mentioned. The race or ethnicity of the operators was not controlled for. The number of operators other than those of White race was small (ranging from < 1%–3%) such that it would have been difficult to stratify by race. Moreover, it was not possible to have adequate statistical power to measure differences by race. Smoking status was not controlled for. The survey focused on occupational exposures and did not include lifestyle questions. Additionally, the specific types of skin cancers were unknown because the survey did not collect data on specific skin cancer types. It is also likely that there are many undiagnosed skin cancer cases in this study population. The use of PPE for skin exposures was also unknown because this information was not obtained in the surveys. Moreover, there might be other potential confounding exposures to different chemical and biological agents that were not accounted for in the study. Therefore, the results of this study should be interpreted with caution, considering these limitations.

To further inform and guide interventions, additional research is necessary. Quantifying farmers' sun UVR exposure and specific agrochemical and organic compounds is essential, even though data collection in these areas can be challenging and often limited due to cost, time, and number of participants. Exploring farmers' current usage of PPE and the impact of this type of protective technique on skin cancer risk could provide valuable insights for designing effective interventions. Additionally, collecting data on the incidence and prevalence of melanoma from cancer databases could be beneficial. However, it is important to note that NMSC is not adequately tracked by surveillance systems in the United States. Consequently, collecting data on NMSC could enhance the robustness of future studies.

5 | Conclusion

Overall, this study highlights the significance of skin as a crucial source for occupational-related exposures among farmers, necessitating attention and improvement in interventions to minimize in this occupational population. Particularly, skin exposure to pesticides/fertilizers and fuels/solvents/paints showed associations with an increased odds of skin cancer in farm and ranch operators. Moreover, further investigation is warranted in the case of livestock producers to identify specific practices or products that might contribute to an elevated risk of skin cancer.

Author Contributions

Sarah Tucker contributed to the conceptualization of the study. Sarah Tucker and Rishad Ahmed curated the data. Sarah Tucker, Yi Du, and Gleb Haynatzki contributed to the methodology and data analysis. Sarah Tucker drafted the manuscript. Risto Rautiainen and Gleb Haynatzki supervised the project. Risto Rautiainen acquired the funding and provided resources. Sarah Tucker agrees to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved. All authors were involved in the interpretation of the data, provided critical reviews of the manuscript, and participated in the final approval.

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Ethics Statement

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

Conflicts of Interest

The authors declare no conflicts of interest.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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