INTERNATIONAL PERSPECTIVES ON HEALTH AND SAFETY AMONG DAIRY WORKERS: CHALLENGES, SOLUTIONS AND THE FUTURE

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INTERNATIONAL PERSPECTIVES ON HEALTH AND SAFETY AMONG DAIRY WORKERS: CHALLENGES, SOLUTIONS AND THE FUTURE

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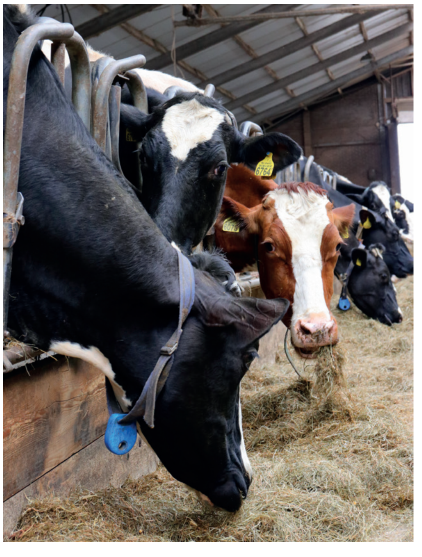

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This e-book provides the insight into occupational health and safety problems, challenges and solutions of the dairy sector. Thirty-two authors have been sharing their results and knowledge reflecting the challenges from small scale farming up to industrial style.

The worldwide trend of growing farm sizes and a reduction in numbers is one of the major drivers for the changes in the working environment.

Musculoskeletal disorders are among the most prevalent health problems of people working on farms. Nevertheless mechanisation has not reduced the number of complaints, and new problems arise due to the changing working environment.

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EDITORIAL
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Editorial: International Perspectives on Health and Safety among Dairy Workers: Challenges, Solutions and the Future

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Keywords: dairy, milking parlor, workload assessment, parlor worker, risk control

Editorial on the Research Topic

International Perspectives on Health and Safety among Dairy Workers: Challenges, Solutions and the Future

The purpose of this special topics edition of Frontiers in Public Health was to present an international perspective on current occupational health research related to workers in the dairy industry. The 32 contributing authors were occupational health researchers from eight countries, including Argentina, Finland, Ireland, Italy, Spain, Sweden, Uganda, and the United States. The majority of authors were part of the International Dairy Research Consortium, a group of international dairy researchers focused on improving the health and safety of dairy workers throughout the world. In the first year of publication, there were approximately 16,000 views and 1,800 article downloads of the 10 published papers.

Milking cows is one of the major work tasks on dairy farms regardless of herd size. The occupational risks associated with milking cows are just as significant for the Latino worker (Menger et al.; Menger et al.) in a large herd American dairy as they are for the Ugandan farmer (Lunner-Kolstrup and Ssali) with five dairy cows. The perception of milk production by consumers in developed countries is an industry that is primarily automated. Although milking tasks have changed in modern milking parlors, parlor workers still experience work-related aches and pain and have more accidents compared to other professions (Pinzke). In this issue, researchers present comprehensive workload analyses and reported that preparing the udder and attaching the milking cluster is associated with awkward postures and high muscular loads of the upper-limb among dairy workers (Mixco et al.; Masci et al.). Other than robotic milking (Karttunen et al.), there are few mechanical interventions that completely eliminate the physical work exposures that are associated with musculoskeletal disorders among dairy parlor workers. Occupational challenges, such as awkward working postures, repetitive tasks, long or unfavorable working hours, cold or hot and wet working environments, significant time pressures, and high workloads do little to attract the next generation to take up this profession.

There has been a worldwide trend of increasing farm size with a simultaneous reduction in the number of farms (Pinzke). Increasing farm size requires hiring more workers, often in regions where the only labor source available are immigrant laborers. Additionally, farm owners need to learn how to manage and train a very diverse workforce in farm operations, including health and safety. Among the published articles, four address the issue regarding health and safety and worker training. Menger et al. and Menger et al. state in their conclusions that the management has a large impact on worker perception of health and safety. Managements' leadership skills are of major importance.

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Clear communication of tasks, addressing health and safety, providing adequate tools, or giving feedback reduces frustration and increases job satisfaction. Rovai et al. present the development of a unique series of short weekly toolbox talks to train immigrant dairy workers on issues related to animal care, cow comfort, and personal safety. The outcomes resulting from the dairy toolbox talks included increased knowledge, greater safety awareness, and enhanced job satisfaction for the workers. Finally, Menger et al. and Menger et al. suggest that the development of dairy training programs emphasize and consider the cultural uniqueness of the target population. Cultural specification of training is a significant issue as the majority of dairy workers in developed countries are immigrants. This issue is also emphasized by Lunner-Kolstrup and Ssali who investigated a very different situation of small-scale dairy farmers in Uganda. Additionally, Furey et al. addressed the role of financial threats on the mental wellbeing of dairy farmers. This is an important issue because of increasing farm sizes and new, highly sophisticated technologies that require significant resources, while both are occurring in an economy of volatile milk prices.

Although requiring significant financial investment, one of the most effective measures of reducing the workload on a dairy farm is investing in automatic milking systems (milking robots). Karttunen et al. describe the health and safety situation of Finnish farms with milking robots. A robot can reduce labor and musculoskeletal risk, but also creates new stresses and challenges for the farmer. Finally, Manbeck et al. discuss the dangers of on-farm manure storage pits that contain both toxic and asphyxiating gases such as hydrogen sulfide, carbon dioxide, methane, and ammonia. The authors present online design aids to evaluate manure pit ventilation systems that would reduce entry risk.

AUTHOR CONTRIBUTIONS

Both authors contributed equally.

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Comparison of Working Conditions and Prevalence of Musculoskeletal Symptoms among Dairy Farmers in Southern Sweden over a 25-Year Period

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Working conditions and the prevalence of perceived musculoskeletal symptoms (MSSs) among dairy farmers in 2013 were monitored by repeating a mail survey of dairy workers in Scania, southern Sweden, using the same method for collecting data on MSSs and working conditions employed in previous surveys conducted in 1988 and 2002. All dairy enterprises in Scania (total 419) were sent two copies of a questionnaire. One or more responses were received from 232 enterprises (55.4%), of which those from 247 dairy farmers (75% men and 25% women) in 199 enterprises are included in this study. The farmers had increased their weekly working hours in 2013 compared with 2002 (males $\bar{x}$ = 43.9, 40.7; females $\bar{x}$ = 37.9, 33.9). Each male milked on average 30 cows in 1988, 44 cows in 2002, and 86 cows in 2013. The corresponding numbers milked by female farmers were 29, 60, and 102, respectively. In 1988, almost all farmers used tethered systems, while in 2013, 54.4% of male and 66.1% of female farmers instead worked with loose-housing systems. Of the farmers who used loose-housing systems, 50.7% had a robotic milking system. In 2013, 79.0% of male and 88.5% of female farmers reported MSSs on some occasion, especially in the lower back, shoulders, and knees for men, and in the shoulders, lower back, and wrists/hands for women. However, there was no statistical change compared with the frequency of MSSs in 2002. In 2013, there was a tendency for younger dairy farmers (≤35 years) to report MSSs, especially in the shoulders, elbows, lower back, and feet, more frequently than younger farmers in 2002. The males who worked with robot milking systems in 2013 indicated less discomfort in the shoulders than men who worked with other systems. The corresponding females indicated fewer problems in the lower back in 2013. Various aspects of milking system design and technology have been improved to reduce the workload and prevent MSSs in dairy farmers. Nevertheless, more improvements are needed to make the milking process more attractive and reduce health problems, especially in younger farmers currently working with milking and in new recruits.

Keywords: musculoskeletal symptoms, survey, physical exposure, ergonomics, agriculture, dairy farming

INTRODUCTION

Dairy Farming and Musculoskeletal Symptoms

Dairy farming in the developed countries worldwide has undergone intensive rationalization over recent decades, leading to fewer operations but larger herd size (1–4). Along with this rationalization, there has been a transition from manual milking in tethered (stanchion) systems to machine milking in loose-housing systems. In tethered systems, which are often used in small-scale dairy farms with smaller herd size (5, 6), the cows are tethered in separate stalls while they are milked. The dairy farmer brings the milking equipment to the cows and stands in between them, kneeling or squatting to perform the work (5, 7). In small-scale dairy farms, it is often the farmer himself who also has to perform other strenuous tasks in addition to milking, such as manual scraping of manure, handling of feed, strewing of litter, and cleaning (8). In loose-housing systems that are more popular among larger dairy farms (7, 9), the milking takes place in a dedicated facility where the milking equipment is stationary. The farm worker performs the milking tasks standing in a more upright posture, either in a milking pit below the cows or at a rotary where the cows pass by on an elevated platform (5, 7, 9). In large-scale dairy farms, the workers are often assigned specific farm operations, such as milking, doing the same highly repetitive and specialized tasks for an entire work shift (8–11).

Automatic milking systems where the milking is performed by robots in milking stations, without depending on human labor, have been used for 20 years in Europe, but have only recently become more popular in North America, in smaller herds with one station and in larger herds with several robotic stations (7, 12, 13).

It is well documented that the milking work in tethered systems is physically demanding, associated with lifting heavy objects, moving and carrying equipment, and awkward working postures, all which are risk factors for development of musculoskeletal symptoms (MSSs), especially in the shoulders, lower back, and knees (5, 10, 14, 15). The repetitive and monotonous milking work in loose-housing systems is considered to pose risk factors for developing MSSs in the upper extremities, especially in the shoulders and wrists/hands (8–10, 15–20).

TABLE 1 | Number of farms and total number of farmers, divided into males and females, included in the surveys in 2013, 2002, and 1988, and response rates to the questionnaire.

Year	No. of farms	No. of farmers	Male	Female	Response rate (%)
2013	199	247	186	61	55
2002	504	686	494	188	67
1988	1058	1465	1077	388	81

Swedish Conditions

In 1990, there were 25,921 farm businesses with dairy cows in Sweden. However, by 2000, this number had fallen to 12,676, in 2010 to 5619, and in 2013 down to 4668 businesses. The average

TABLE 2 | Description and comparison of dairy farmers and their work situation in 1988, 2002, and 2013.

		2013				2002				1988			
		n	Mean[e]	SD	Range	*n*	Mean[e/f]	SD	Range	*n*	Mean[e/g]	SD	Range
Age (year)	Males	184	53.5[d]	10.98	21–83	493	49.4[b/d]	11.00	20–79	1077	47.7[c/c]	11.89	15–81
	Females	61	46.3	13.60	19–71	188	47.3	10.60	20–68	388	45.8	10.89	19–75
No. of years as a dairy farmer	Males	185	32.6[d]	12.24	3–70	494	26.6[d/d]	12.21	1–55	1074	26.1[d]	14.16	1–65
	Females	60	21.8	13.36	1–50	186	20.6	10.83	2–57	386	21.3	13.42	1–50
Hours worked per week	Males	182	43.9[b]	16.89	7–119	490	40.7[d/b]	14.58	2–112	1066	36.3[d/d]	12.39	4–85
	Females	60	37.9	15.75	12–100	187	33.9[/a]	13.10	4–70	379	27.7[/d]	10.86	3–88
Body weight (kg)	Males	184	84.2[d]	11.62	58–116	492	82.0[d/b]	10.70	58–135	1067	79.4[d/d]	9.91	42–122
	Females	60	70.2	12.11	50–100	178	69.5	10.75	45–100	377	65.6[/d]	8.77	50–100
Body height (cm)	Males	185	180.9[d]	7.10	157–200	490	179.6[d/b]	6.79	152–200	1069	177.7[d/d]	6.46	150–205
	Females	60	167.3	6.15	150–181	183	166.9	5.72	150–185	382	165.4[/c]	5.81	150–182
Body mass index (kg/m^2)	Males	183	25.7	3.16	18.6–36.8	488	25.4	2.95	18.2–41.7	1065	25.1[/a]	2.76	17.0–36.8
	Females	60	25.1	3.95	17.9–35.9	177	25.0	3.77	17.6–39.1	375	24.0[/c]	2.97	17.9–34.6
No. of cows milked	Males	185	85.8	72.72	8–650	492	55.7[/d]	44.16	3–320	1077	30.1[/d]	24.74	2–300
	Females	60	102.3	82.39	8–420	188	59.2[/d]	47.23	12–320	386	29.3[/d]	17.98	1–160

Descriptive values (n, mean, SD, and range), divided by sex.
[a]*$p < 0.10$.*
[b]*$p < 0.05$.*
[c]*$p < 0.01$.*
[d]*$p < 0.001$.*
[e]*Differences between sexes (independent samples t-test).*
[f]*Differences between dairy farmers in 2013 and 2002 (independent samples t-test).*
[g]*Differences between dairy farmers in 2002 and 1988 (independent samples t-test).*
Significant increases in values between the 2002 and 2013 surveys are marked in red.
The superscript "/" separates the significant levels (a, b, c, d) of the tests with respect to sex (test e) and survey years (tests f, g).

herd size increased over the period, from 22 cows in 1990 to 34 cows in 2000, 62 cows in 2010, and 74 cows in 2013 (21–24).

Most large dairy herds (both in numbers and as a percentage) are located in the province of Scania in southern Sweden. The number of herds in Scania with more than 75 cows increased from 76 in 1990 to 130 in 2000 and to 179 in both 2010 and 2013, while the total number of dairy farms in Scania decreased in those years from 2718 to 1198, 510, and 419, respectively (21–24).

Earlier studies in 1988 and 2002 on dairy farmers in Scania showed that the rationalization described above, along with mechanization and automation of the work, had resulted in a change in pattern concerning working conditions and health for individual farmers (14, 15). In 2002, 83% of male and 90% of female dairy farmers surveyed in Sweden reported some form of perceived MSSs during the previous 12 months. This was an increase compared with the survey in 1988, especially as regards problems in the neck, shoulders, and wrists/hands. By 2002, milkers had increased, on average, their working hours per week, the number of cows milked, and the use of more milking units (15).

In 1988, almost all dairy farmers were working in traditional tethered systems, whereas in 2002, about 25% were working in loose-housing systems (15).

Most dairy farmers in both the 1988 and 2002 survey, irrespective of age or sex, thought that silage handling and milking were their most strenuous tasks. However, the milkers derived their greatest pleasure from the actual milking task, as well from their work with caring for the animals (15).

Overall, the earlier studies (14, 15) showed that individual factors, such as sex, age, and weight, as well as those factors related to work organization and the physical workplace, such as number of hours worked per week, number of cows milked, the milking system used, and the age of the farm building, had significant impacts on the prevalence of MSSs.

TABLE 3 | Description and comparison of the dairy farmers and their work situation in 1988, 2002, and 2013.

			2013		2002		1988	
			n	%[e]	*n*	%[e/f]	*n*	%[e/g]
Employment form	Males	Employed	9	5.0[d]	29	6.1[d]	45	4.2
		Self-employed	171	95.0	446	93.9	1032	95.8
	Females	Employed	12	19.7	28	15.5	10	2.6[/d]
		Self-employed	49	80.3	153	84.5	378	97.5
Handedness	Males	Right	175	94.1	445	89.9[/a]	994	92.3
		Left	6	3.2	38	7.7	68	6.3
		Ambidextrous	5	2.7	12	2.4	15	1.4
	Females	Right	57	93.4	176	92.6	359	92.5
		Left	4	6.6	11	5.8	21	5.4
		Ambidextrous	0	0	3	1.6	8	2.1
Housing system	Males	Tethered	83	45.6	365	74.0[/d]	1032	95.8[b/d]
		Loose-housing	87	47.8	115	23.3	24	2.2
		Both	12	6.6	13	2.6	21	1.9
	Females	Tethered	20	33.9	135	71.4[/d]	381	98.2[/d]
		Loose-housing	35	59.3	46	24.3	3	0.8
		Both	4	6.8	8	4.2	4	1.0
Building date	Males	-1969	15	8.2	31	6.4[/d]	332	31.2[/d]
		1970–1979	23	12.6	117	24.0	491	46.2
		1980–1989	28	15.4	110	22.5	240	22.6
		1990–1999	42	23.1	197	40.4		
		2000–2009	53	29.1	33	6.8		
		2010-	21	11.5				
	Females	-1969	4	6.6	11	6.0[/d]	104	27.1[/d]
		1970–1979	9	14.8	44	23.9	190	49.5
		1980–1989	6	9.8	42	22.8	90	23.4
		1990–1999	10	16.4	72	39.1		
		2000–2009	19	31.1	15	8.2		
		2010-	13	21.3				

Frequency values (n and %), divided by sex.
[a] $p < 0.10$.
[b] $p < 0.05$.
[c] $p < 0.01$.
[d] $p < 0.001$.
[e] *Differences between sexes (Mann–Whitney U test).*
[f] *Differences between dairy farmers in 2013 and 2002 (Mann–Whitney U test).*
[g] *Differences between dairy farmers in 2002 and 1988 (Mann–Whitney U test).*
Significant increases in values between the 2002 and 2013 surveys are marked in red and significant decreases in green.
The superscript "/" separates the significant levels (a, b, c, d) of the tests with respect to sex (test e) and survey years (tests f, g).

TABLE 4 | Frequency of perceived symptoms [number (*n*) and %] in the musculoskeletal system at some time during the past 12 months among dairy farmers, divided by sex, in 2013, 2002, and 1988.

		2013		2002		1988	
		n	%[e]	*n*	%[e/f]	*n*	%[e/g]
Neck	Males	50	26.9	139	30.8[b]	229	21.3[c/d]
	Females	20	32.8	72	39.1	112	28.9[/b]
Shoulders	Males	71	38.2[c]	198	43.6[c]	366	34.0[c/d]
	Females	39	62.3	107	58.8	166	42.9[/d]
Elbows	Males	30	15.1	93	20.4[b]	189	17.6[b]
	Females	9	14.8	50	27.8[/b]	87	22.5
Wrists/hands	Males	28	15.1[d]	111	24.3[d/b]	172	16.0[d/d]
	Females	30	49.2	85	46.2	131	33.9[/c]
Upper back	Males	17	9.1[b]	51	11.5	91	8.5[b/a]
	Females	12	19.7	28	15.2	47	12.2
Lower back	Males	99	53.2	247	53.6	594	55.5[b]
	Females	31	50.8	86	46.7	188	48.6
Hips	Males	50	26.9	124	27.6[a]	271	25.3
	Females	14	23.0	63	34.4[/a]	100	25.8[/b]
Knees	Males	64	34.4	174	37.7	429	40.0
	Females	21	34.4	61	33.2	145	37.5
Feet	Males	28	15.1	65	14.3	113	10.5[c/b]
	Females	12	19.7	36	19.6	60	15.5
Any body part	Males	147	79.0[a]	397	83.4[b]	872	81.2
	Females	54	88.5	166	89.7	326	84.2[/a]

[a]$p < 0.10$.
[b]$p < 0.05$.
[c]$p < 0.01$.
[d]$p < 0.001$.
[e]*Differences between sexes (Pearson chi-square test).*
[f]*Differences between dairy farmers in 2013 and 2002 (Pearson chi-square test).*
[g]*Differences between dairy farmers in 2002 and 1988 (Pearson chi-square test).*
Significant decreases in values between the 2002 and 2013 surveys are marked in green.
The superscript "/" separates the significant levels (a, b, c, d) of the tests with respect to sex (test e) and survey years (tests f, g).

The primary aim of the present study was to monitor the current prevalence of MSSs, individual conditions, and the work situation among Scanian dairy farmers by repeating the previous surveys from 1988 and 2002. The objective was to clarify trends on the prevalence of MSSs and the effects on farmers of an additional 10 years of exposure to their work environment, especially to the risk factors found in the previous surveys. The secondary aim was to describe some good practices and technical aids and solutions that can be adopted in different milking systems managed by dairy farmers in order to reduce the workload and prevent MSSs.

MATERIALS AND METHODS

The same questionnaire as was used in 1988 and 2003 was employed in the present survey. It comprised questions on perceived MSSs based on the standardized Nordic Musculoskeletal Questionnaires (25), as well as questions about personal characteristics and working conditions. These included items such as the number of cows milked per day, the milking system used, technical aids, occurrence of injuries and health problems beside MSSs, degree of mechanization of the work, which work task the respondents considered to be the most strenuous and which gave the most job satisfaction (26, 27). The questions used regarding MSSs were whether the respondents at some time had (yes/no) perceived ache, pain, or discomfort in the neck, shoulder, elbow, wrist/hand, upper back, lower back, hip, knee, and/or feet during the previous 12 months.

The names and addresses of all dairy farm businesses in Scania (in total 419) listed in the national Farm Register (LBR, 2013) were obtained from the Swedish Board of Agriculture. Each business received two questionnaires by mail in April 2014, enabling two people involved daily, or more regularly, in the milking work (i.e., milkers), e.g., husband and wife, owner and employee, or two employees, to respond. Two reminders were sent out in May 2014 to obtain an acceptable response rate. The first reminder consisted of only a reminder card with a request to complete the questionnaire, whereas with the second reminder, two new questionnaires were sent to those farmers who did not answer the first mailing. In this second mailing, there was also an opportunity to indicate the reason for not participating in the survey.

Of the 418 dairy businesses to which the survey was sent (one business did not receive a mailing because it had an address abroad), 232 businesses responded (55.4%) and 33 did not return a completed questionnaire. Of the latter, 14 had ceased production, were not milking, had no cows, or were deceased; 6 cited lack of time; 5 cited other reasons; and 8 did not state any reason why they did not participate in the study. This means that 247

TABLE 5 | Description and comparison of dairy farmers with and without reported musculoskeletal symptoms in 2013.

		Symptoms 2013				No symptoms 2013			
		n	**Mean[e]**	**SD**	**Range**	***n***	**Mean[e/f]**	**SD**	**Range**
Age (year)	Males	147	53.5[d]	10.96	21–83	37	53.5	11.17	26–72
	Females	54	45.9	13.57	19–70	7	49.3	14.56	29–71
	Total	201	51.5	12.17	19–83	44	52.8	11.68	26–72
No. of years as a dairy farmer	Males	146	32.6[d]	12.15	4–70	39	32.9[b]	12.73	3–60
	Females	53	21.8	13.56	1–50	7	21.9	12.66	2–40
	Total	199	29.7	13.38	1–70	46	31.2	13.20	2–60
Hours worked per week	Males	143	42.6[a]	16.11	7–119	39	48.7[/b]	18.94	20–105
	Females	53	37.6	15.32	12–100	7	40.0	20.0	20–70
	Total	196	41.2	16.01	7–119	46	47.4[/b]	19.13	20–105
Body weight (kg)	Males	145	84.7[d]	11.53	58–116	39	82.3[c]	11.94	59–110
	Females	53	70.4	12.25	50–100	7	68.7	11.76	55–91
	Total	198	80.9	13.31	50–116	46	80.2	12.77	55–110
Body height (cm)	Males	147	181.0[d]	7.10	157–200	38	180.4[d]	7.14	170–193
	Females	53	167.5	6.30	150–181	7	165.9	5.05	160–172
	Total	200	177.4	9.13	150–200	45	178.2	8.65	160–193
Body mass index (kg/m^2)	Males	145	25.9	3.10	19.9–36.8	38	25.2	3.38	18.6–35.3
	Females	53	25.1	4.04	17.9–35.9	7	25.0	3.77	20.2–30.8
	Total	198	25.7	3.39	17.9–36.8	45	25.2	3.35	18.6–35.3
No. of cows milked	Males	146	82.6[b]	60.18	8–360	39	97.5	107.75	12–650
	Females	54	104.3	85.35	8–420	6	84.2	49.34	25–150
	Total	200	88.5	68.35	8–420	45	95.7	101.61	12–650

Descriptive values (n, mean, SD, and range), divided by sex.
[a]$p < 0.10$.
[b]$p < 0.05$.
[c]$p < 0.01$.
[d]$p < 0.001$.
[e]*Differences between sexes (independent samples t-test).*
[f]*Differences between dairy farmers with and without musculoskeletal symptoms in 2013 (independent samples t-test).*
Significant decreases in values between no symptoms and symptoms are marked in green.
The superscript "/" separates the significant levels (a, b, c, d) of the tests with respect to sex (test e) and farmers with and without symptoms (test f).

milker responses from 199 farm businesses were treated in the present study and were compared with the data collected in 1988 and 2002 (**Table 1**).

Data Analysis

Descriptive statistics regarding demographics, working hours, employment, milking systems, herd size, age of farm buildings, and perceived MSSs, represented by number (n), frequency (%), mean, SD, range, and statistical tendency and significance, are presented by gender and survey year in **Tables 2–4**; by gender and MSSs/no MSSs in 2013 in **Tables 5** and **6**; by gender and milking robot/other systems in 2013 in **Table 7**; and by gender, age, and survey year in **Table 8**.

For statistical analysis of the results, independent samples t-tests, Mann–Whitney U tests, and chi-square analyses were applied using SPSS version 22 (28). If one cell contained an expected count <5, Fisher's exact test was used. Otherwise, Pearson's chi-square was calculated. The probability limits for evaluating statistical tendency ([a]) and significance ([b,c,d]) were [a]$p < 0.10$, [b]$p < 0.05$, [c]$p < 0.01$, and [d]$p < 0.001$. Significant increases in values between the 2002 and 2013 surveys are marked in red in the tables and significant decreases in green.

Ethical Considerations

Ethical approval of the Regional Ethical Review Board for studies involving humans was not considered necessary for the survey. The questionnaire was completed anonymously, meaning that no individual or workplace affiliation could be identified. Processing of personal data was performed according to the Personal Data Act (Swedish Code of Statutes, SFS 1998:204), the purpose of which is to protect the individual's integrity. Overall, the national guidelines based on the World Medical Association Declaration of Helsinki concerning research ethics (29), anonymity, voluntariness, confidentiality, and archiving of data were considered and fulfilled.

RESULTS

Demographics, Working Hours, Employment, Milking Systems, Herd Size, and Age of Farm Buildings

Of the total of 247 respondents in 2013, 186 (75.3%) were men and 61 (24.7%) were women.

Compared with the female dairy farmers surveyed, male farmers were on average 7 years older ($\bar{x}$ = 53.5, 46.3;

TABLE 6 | Description and comparison of dairy farmers with and without musculoskeletal symptoms in 2013.

			Symptoms 2013		No symptoms 2013	
			n	%[e]	*n*	%[e/f]
Employment form	Males	Employed	8	5.6[c]	1	2.7
		Self-employed	135	94.4	36	97.3
	Females	Employed	12	22.2	0	0.0
		Self-employed	42	77.8	7	100.0
	Total	Employed	20	10.2	1	2.3
		Self-employed	177	89.8	43	97.7
Handedness	Males	Right	137	93.2	38	97.4
		Left	5	3.4	1	2.6
		Ambidextrous	5	3.4	0	2.4
	Females	Right	51	94.4	6	85.7
		Left	3	5.6	1	14.3
		Ambidextrous	0	0.0	0	0.0
	Total	Right	188	93.5	44	95.7
		Left	8	4.0	2	4.3
		Ambidextrous	5	2.0	0	0.0
Housing system	Males	Tethered	66	46.2	17	43.6
		Loose-housing	68	47.6	19	48.7
		Both	9	6.3	3	7.7
	Females	Tethered	18	30.0	2	33.3
		Loose-housing	31	62.0	4	66.7
		Both	4	8.0	0	0.0
	Total	Tethered	84	42.9	19	42.2
		Loose-housing	99	50.5	23	51.1
		Both	13	6.6	3	6.7
Building date	Males	-1999	90	62.9[a]	18	46.2[/a]
		2000-	53	37.1	21	53.8
	Females	-1999	26	48.1	3	42.9
		2000-	28	51.9	4	57.1
	Total	-1999	116	58.9	21	45.7
		2000-	81	41.1	25	54.3

Frequency values (n and %), divided by sex.
[a]*$p < 0.10$.*
[b]*$p < 0.05$.*
[c]*$p < 0.01$.*
[d]*$p < 0.001$.*
[e]*Differences between sexes (Pearson chi-square test).*
[f]*Differences between dairy farmers with and without musculoskeletal symptoms in 2013 (Pearson chi-square test).*
Significant increases in values between no symptoms and symptoms are marked in red and significant decreases in green.
The superscript "/" separates the significant levels (a, b, c, d) of the tests with respect to sex (test e) and farmers with and without symptoms (test f).

$p = 0.000$), had worked 11 years longer as a dairy farmer ($\bar{x} = 32.6, 21.8$; $p = 0.000$), and worked 6 h more per week ($\bar{x} = 43.9, 37.9$; $p = 0.016$) (**Table 2**).

Both male and female farmers had increased their working hours, by 3 and 4 h/week, respectively, in 2013 compared with 2002 (males $\bar{x} = 43.9, 40.7$; $p = 0.016$; females $\bar{x} = 37.9, 33.9$; $p = 0.055$). The men in 2013 were about 3 cm taller and weighed about 2 kg more than the men in 2002 (**Table 2**). Each male milked on average 30 cows in 1988, 44 cows in 2002, and 86 cows in 2013. The increase between years was significant ($p = 0.000$ and $p = 0.000$, respectively). The corresponding number of cows milked by female farmers in 1988, 2002, and 2013 was 29, 60, and 102, respectively (difference $p = 0.000$ and $p = 0.000$, respectively) (**Table 2**).

Women were more frequently farm employees (rather than managers/owners) than their male colleagues in 2013 (19.7 vs. 5.0%; $p = 0.000$) (**Table 3**).

In 1988, almost all farmers used a tethered system and only 4.1% of male farmers worked with a loose-housing system. This figure increased to 25.9% in 2002 and 54.4% in 2013 ($p = 0.000$ and $p = 0.000$, respectively). The corresponding increase for female farmers was from 1.8% in 1988 to 28.5% in 2002 and 66.1% in 2013 ($p = 0.000$ and $p = 0.000$, respectively) (**Table 3**).

About half (50.7%) of the farmers who stated that they used a loose-housing system had a robotic milking system.

In 2013, more than 40% of men and 50% of women worked in farm buildings built in 2000 or later (**Table 3**).

Musculoskeletal Symptoms

About 79.0% of men and 88.5% of women reported MSSs at some time in 2013, whereas in 2002, 83.4% of men and 89.7% of women indicated MSSs. This change was not significant ($p = 0.187$ and $p = 0.791$ for men and women, respectively). As in 2002, in 2013, men more often reported symptoms in lower back (53.2%),

TABLE 7 | Frequency in 2013 of perceived symptoms [number (*n*) and %] in the musculoskeletal system at some time during the past 12 months among dairy farmers, divided by sex, working with a milking robot and other systems.

		Milking robot		Other system	
		n	%[e]	*n*	%[e/f]
Neck	Males	10	19.6	39	29.8
	Females	5	26.3	15	37.5
	Total	15	21.4	54	31.6
Shoulders	Males	14	27.5[a]	54	41.2[c/a]
	Females	10	52.6	27	67.5
	Total	24	34.3	81	47.4[/a]
Elbows	Males	10	19.6	18	13.7
	Females	3	15.8	6	15.0
	Total	13	18.6	24	14.0
Wrists/hands	Males	8	15.7[b]	18	13.7[d]
	Females	9	47.4	21	52.5
	Total	17	24.3	39	22.8
Upper back	Males	4	7.8	13	9.9[b]
	Females	2	10.5	10	25.5
	Total	6	8.6	23	13.5
Lower back	Males	26	51.0	70	53.4
	Females	5	26.3	25	62.5[/b]
	Total	31	44.3	95	55.6
Hips	Males	9	17.6	38	29.0
	Females	4	21.1	10	25.0
	Total	13	18.6	48	28.1
Knees	Males	21	41.2	41	31.3
	Females	6	31.6	15	35.0
	Total	27	38.6	55	32.2
Feet	Males	7	13.7	21	15.3
	Females	3	15.8	9	22.5
	Total	10	14.3	29	17.0
Any body part	Males	39	76.5	104	79.4
	Females	17	89.5	36	90.0
	Total	56	80.0	140	81.9

[a]*p < 0.10.*
[b]*p < 0.05.*
[c]*p < 0.01.*
[d]*p < 0.001.*
[e]*Differences between sexes (Pearson chi-square test).*
[f]*Differences between dairy farmers working with and without milking robot in 2013 (Pearson chi-square test).*
Significant decreases in values between symptoms in other symptoms and symptoms in robot systems are marked in green.
The superscript "/" separates the significant levels (a, b, c, d) of the tests with respect to sex (test e) and farmers with and without milking robot systems (test f).

shoulders (38.2%), and knees (34.4%). The women surveyed in 2013 most often reported discomfort in shoulders (62.3%), lower back (50.8), and wrists/hands (49.2%). This pattern was the same as in 2002. No significant change in the frequency of MSSs in 2013 compared with 2002 was observed in the three most frequent body regions for either men or women (**Table 4**).

The men in 2013 who stated that they had experienced trouble in some body region worked an average of 6 h less per week than the men who did not report any such trouble (**Table 5**). In addition, they worked more often in older buildings (**Table 6**).

Both men and women reported symptoms at some time in 2013 equally frequently, about 80 and 90% respectively, regardless of whether they worked in a tethered system or loose-housing system (**Table 6**). However, the men who worked with a milking robot reported significantly fewer symptoms in the shoulders than the men who worked in other systems. The women who worked with a milking robot reported fewer problems in the lower back (**Table 7**).

The younger dairy farmers (≤35 years) in 2013 more often reported discomfort in the shoulders ($p = 0.054$), elbows ($p = 0.020$), lower back ($p = 0.058$), and feet ($p = 0.076$) compared with 2002, while the older farmers (55 years and older) reported fewer problems with the neck ($p = 0.034$), shoulders ($p = 0.084$), elbows ($p = 0.005$), wrists/hands ($p = 0.004$), and knees ($p = 0.081$) (**Table 8**).

Aids and Facilities

In the tethered systems, the following facilities were used: milking stool (48.5%) (**Figure 1**), "kangaroo bag" [a belt to wear containing a bottle holder and large bags for carrying milking towels (28.2%)], rubber mat on the floor (33.0%) (**Figure 2**), milking rail (36.9%) (**Figure 3**), and automatic cluster removal (32.0%) (**Figure 4**). In loose-housing systems, farmers used kangaroo bag (3.3%), rubber mat on the floor (7.4%), automatic cluster removal (39.3%), height-adjustable floor (18.0%) (**Figure 5**), and support arm (10.7%) (**Figure 6**).

Manure and Feed Handling

In loose-housing systems, both manure management and feed handling were more mechanized than in tethered systems. About 86% used a pressure washer in loose housing, compared with 83% in tethered systems.

Health Problems and Injuries

Approximately 17% of the dairy farmers surveyed indicated that they had health problems other than MSSs arising from their work in tethered systems, compared with 9% in loose-housing systems. Common symptoms were asthma, allergies, and rashes, but also disorders of the respiratory system such as sneezing, coughing, and colds. The dairy farmers also indicated experiencing fatigue and stress.

A total of 32.8% of dairy farmers had suffered some form of injury at work. Among those who worked in tethered systems, 40.8% had experienced an injury, compared with 30.7% in loose-housing systems. Animal-related injuries dominated, such as kicks, trampling, crushing, and butting by the animals. Fall injuries also occurred in both systems.

Strenuous Duties

Overall, farmers working in tethered systems reported that feed/silage management and milking itself were the most strenuous tasks, while farmers working in loose-housing systems reported cleaning and feeding/handling silage as the most exhausting.

Job Satisfaction

For farmers using the tethered system, working with the animals and the milking itself gave the most job satisfaction, while for those working in loose-housing systems, working with the animals and calves gave the most job satisfaction.

TABLE 8 | Frequency in 2013, 2002, and 1988 of perceived symptoms [numbers (*n*) and %] in the musculoskeletal system at some time during the past 12 months among dairy farmers, divided by sex and age.

		2013						2002						1988					
		≤35 years		36–54 years		≥55 years		≤35 years		36–54 years		≥55 years		≤35 years		36–54 years		≥55 years	
		n	%	*n*	%	*n*	%	*n*	%[e]	*n*	%[e]	*n*	%[e]	*n*	%[f]	*n*	%[f]	*n*	%[f]
Neck	Males	4	30.8	22	31.9	24	23.5	14	24.1	71	30.1	53	34.2[a]	22	11.4[b]	118	22.6[b]	89	24.8[b]
	Females	7	43.8	9	32.1	4	23.5	9	39.1	44	40.0	18	36.7	20	23.3	69	31.8	23	27.4
	Total	11	37.9	31	32.0	28	23.5	23	28.4	115	33.2	71	34.8[b]	42	15.1[c]	187	25.3[c]	112	25.3[b]
Shoulders	Males	5	38.5	26	37.7	40	39.2	18	30.0	93	39.9	84	53.2[b]	38	19.7[a]	187	35.8	141	39.3[c]
	Females	12	75.0	14	50.0	12	70.6	14	58.3	65	60.7	27	55.1	35	40.7	101	46.5[b]	30	35.7[b]
	Total	17	58.6	40	41.2	52	43.7	32	38.1[a]	158	46.5	111	53.6[a]	73	26.2[b]	288	38.9[b]	171	38.6[d]
Elbows	Males	2	15.4	14	20.3	12	11.8	2	3.4	51	21.3	39	25.2[c]	13	6.8	106	20.3	70	19.6
	Females	2	12.5	5	17.9	2	11.8	0	0.0	39	36.4[a]	11	22.9	10	11.6	60	27.6	17	20.2
	Total	4	13.8	19	19.6	14	11.8	2	2.4[b]	90	26.0	50	24.6[c]	23	8.3[a]	166	22.4	87	19.7
Wrists/hands	Males	2	15.4	14	20.3	12	11.8	13	22.8	55	23.0	43	27.4[c]	31	16.1	78	14.9[c]	63	17.6[b]
	Females	10	62.5	12	42.9	8	47.1	9	37.5	52	47.7	22	44.9	29	33.7	75	34.6[b]	27	32.1
	Total	12	41.4	26	26.8	20	16.8	22	27.2	107	30.7	65	31.6[c]	60	21.6	153	20.7[d]	90	20.4[c]
Upper back	Males	2	15.4	7	10.1	8	7.8	9	16.1	28	12.0	13	8.6	18	9.4	42	8.0[a]	31	8.7
	Females	4	25.0	6	21.4	2	11.8	3	12.5	19	17.4	6	12.2	10	11.6	29	13.4	8	9.6
	Total	6	20.7	13	13.4	10	8.4	12	15.0	47	13.7	19	9.5	28	10.1	71	9.6[b]	39	8.9
Lower back	Males	8	61.5	43	62.3	48	47.1	25	47.1	131	54.8	89	56.0	92	48.4	305	58.3	197	55.0
	Females	10	62.5	15	53.6	6	35.3	10	41.7	55	50.9	20	60.0	37	43.0	112	51.6	39	46.4
	Total	18	62.1	58	59.8	54	45.4	35	41.7[a]	186	53.6	109	52.2	129	46.7	417	56.4	236	53.4
Hips	Males	2	15.4	18	26.1	30	29.4	9	15.3	68	28.6	46	30.7	21	11.0	137	26.2	113	31.6
	Females	1	6.2	8	28.6	5	29.4	3	12.5	38	35.5	21	42.0	12	14.0	63	29.0	25	29.8
	Total	3	10.3	26	26.8	35	29.4	12	14.5	106	30.7	67	33.5	33	11.9	200	27.0	138	31.2
Knees	Males	5	38.5	27	39.1	32	31.4	20	33.9	79	33.3	74	45.7[b]	72	37.3	200	38.3	157	43.9
	Females	5	31.2	8	28.6	8	47.1	6	25.0	36	33.3	18	36.0	22	25.6	83	38.2	40	47.6
	Total	10	34.5	35	36.1	40	33.6	26	31.3	115	33.3	92	43.4[a]	94	33.7	283	38.3	197	44.6
Feet	Males	2	15.4	13	18.8	13	12.7	6	10.2	28	11.7	31	20.4	17	8.8	63	12.0	33	9.2[d]
	Females	4	25.0	6	21.4	2	11.8	1	4.2	25	23.4	9	17.6	4	4.7	38	17.5	18	21.7
	Total	6	20.7	19	19.6	15	12.6	7	8.4[a]	53	15.3	40	19.7	21	7.5	101	13.6	51	11.6[c]
Any body part	Males	11	84.6	56	81.2	80	78.4	50	82.0	200	82.3	144	85.2	140	72.5	441	84.3	291	81.3
	Females	14	87.5	25	89.3	15	88.2	21	87.5	99	90.8	44	88.0	70	81.4	189	87.1	67	79.9
	Total	25	86.2	81	83.5	95	79.8	71	83.5	299	84.9	188	85.8	210	75.3	630	85.1	358	81.0

[a]$p < 0.10$.
[b]$p < 0.05$.
[c]$p < 0.01$.
[d]$p < 0.001$.
[e]*Differences between dairy farmers in 2013 and 2002 (Pearson chi-square test).*
[f]*Differences between dairy farmers in 2002 and 1988 (Pearson chi-square test).*
Significant increases in values between the 2002 and 2013 surveys are marked in red and significant decreases in green.

DISCUSSION

The results of this most recent survey show that milking dairy cows is still associated with a high incidence of MSSs, as found previously among dairy farmers with smaller herd size operations (8, 16, 30) and operations with larger herd size (9).

No statistically significant reduction in the total number of complaints in 2013 was observed compared with 2002, despite the technological developments that have taken place over the last 20 years. A concerning finding was that young dairy farmers (≤35 years) more frequently reported symptoms than the corresponding young dairy farmers in 2002. However, the dairy farmers who were 55 and older reported fewer complaints than in 2002. This may be because older farmers with health complaints had stopped milking due to their problems in the interim and that only the healthy elderly remained in the profession (the so-called healthy worker effect). This effect was also observed in the 2002 study, where more than 20% of those who had stopped milking cited occupational health reasons for this (15). The effect has also been reported in other studies on musculoskeletal disorders among farmers (31) and among pig keepers with lung problems (32).

One advantage of the present study and of the previous two surveys was the availability of a relatively large body of material

FIGURE 1 | Milking stool. ©Christina Lunner Kolstrup.

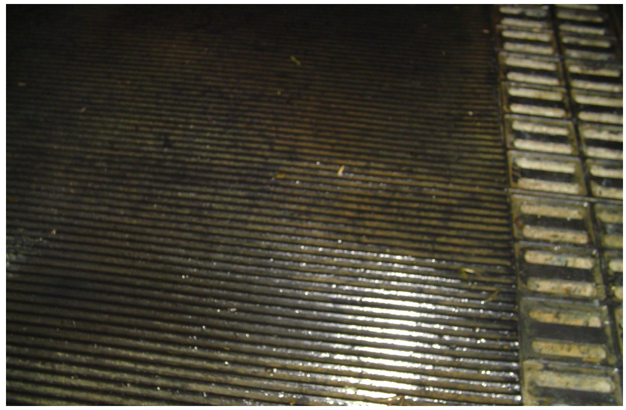

FIGURE 2 | Rubber matting. ©Stefan Pinzke.

FIGURE 3 | Milking rail. ©Christina Lunner Kolstrup.

collected using the same validated and standardized questionnaire for assessment of MSSs, which made it possible to study trends in the prevalence of MSSs among Scanian dairy farmers. However, it was not possible to grade the severity or the type of MSSs, since the relevant questions in the questionnaire only asked if the respondents had at some time experienced MSSs, and did not enquire about the severity or the type of symptoms. For this, more in-depth studies are needed. Moreover, it was not possible to establish causality between MSSs and the risk factors studied, since the present study and the previous surveys were designed as cross-sectional studies where variables were measured at the same time. Therefore, we could not establish whether the MSSs or exposure to the risk factors came first.

In addition to MSSs, dairy farmers suffer work-related injuries. In 2013, approximately one-third of the dairy farmers in Scania reported that they had been injured during work at some time. A previous study of injuries in agriculture showed that on 15% of Swedish dairy farms, at least one accident occurred in 2004 (33). Preliminary results from an ongoing study on injuries in agriculture in 2013 (Pinzke and Lundqvist, manuscript) show no reduction in the number of injuries compared with 2004 when the number of hours worked is taken into account.

Several studies have shown that compared with milking in parlor systems, milking in tethered stall systems involves more loading work postures and more handling of manual materials, which are risk factors for MSSs in the shoulders and lower part of the body. On the other hand, milking in loose-housing systems involves repetitive and monotonous work, which is a risk factor for developing MSSs, especially in the upper extremities (5, 8–10, 14–20). As this study shows, milkers still reported an equally high frequency of MSSs as in the past, regardless of whether they worked in tethered or parlor systems. However, those working

FIGURE 4 | Automatic cluster removal. ©Christina Lunner Kolstrup, Stefan Pinzke.

FIGURE 5 | Adjustable floor. ©Christina Lunner Kolstrup, Stefan Pinzke.

with milking robot systems in 2013 reported fewer MSSs overall, especially in shoulders (men) and lower back (women), compared with those working with other systems. An explanation for this is of course that the robot, instead of the milker, performs most of the heavy, repetitive, and one-sided milking tasks. A reduction in the risk of musculoskeletal problems with robotic milking compared with conventional milking has also been reported in other studies (34). Just over 28% of the Scanian dairy farmers surveyed in 2013 responded that they worked with robotic milking systems. This corresponds fairly well with the incidence of robotic milking (32%) throughout the country (35).

FIGURE 6 | Support arm. ©Christina Lunner Kolstrup, Stefan Pinzke.

Many developments have been made in technical aids and the design of milking systems in order to reduce workloads and prevent musculoskeletal disorders when milking cows (10, 36). In an EU project where SLU was one partner (37), several good practices were observed on farm visits across Belgium, Poland, Sweden, and UK, e.g., installation of milking rails in tethered houses to facilitate transport of milking equipment and adjusting the floor to the height of the farmer in loose-housing systems. Use of perforated rubber matting on existing floors in parlors is another example of good practice that aims to reduce the physical load on the lower limbs and reduce fatigue. Other solutions are designed for specific tasks during milking in parlors; e.g., when cleaning udders, central placement of a basket for drying papers or cloths on a cart reduces both walking distance and exposure to awkward back postures for the milking staff. Installation of a support arm can reduce the workload when attaching the milking cluster to the cow. The use of lightweight clusters and tubes also reduces the load. Instead of using a dip cup for teat dipping, the farmer can spray the cow's teats with disinfectant, thus reducing the reach distance during work. Despite these solutions in place on existing farms, not enough research has been done on specific ergonomic interventions in milking parlors.

Some studies have attempted to find the optimum working height for dairy farmers during milking. Jakob et al. (38) found that the optimum working height when attaching teat cups to the udder is having the cow's teats at shoulder level, while Stål and Pinzke (39) found that the ideal working posture is when the farmer's elbow height is about 30 cm above the floor where the cow is standing.

The technical aids described above, such as an adjustable floor, support arm, and lightweight clusters, can improve the loading conditions for the farmer if they are applied correctly. However, because of the wide variation in the body composition of cows and differences in the body height of dairy farmers, there is still no technical solution to ensure an optimum working position for all workers at all times.

This study showed that milkers in 2013 were still reporting as many MSSs as 10 years earlier, despite the technical solutions that have been introduced in different milking systems to reduce risk factors for developing MSSs, such as awkward working postures and physical workload. At the same time, exposure to other risk factors has increased, e.g., weekly working hours, number of milking cows, and a higher proportion of working in loose-housing systems, where milkers are exposed to monotonous and repetitive work. Thus, there is a need for continued efforts and research to improve the ergonomic conditions on dairy farms in order to make milking work more attractive, with fewer musculoskeletal problems, especially for younger dairy farmers who are currently working with milking, but also to attract new recruits.

AUTHOR CONTRIBUTIONS

The author planned the study, carried out the data collection, analyzed the data, and wrote the article.

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Upper Limb Muscle Activity among Workers in Large-Herd Industrialized Dairy Operations

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Objectives: The primary aim of this cross-sectional research study was to quantify upper limb muscle activity among workers performing milking tasks in large-herd dairy parlors.

Methods: Surface electromyography (sEMG) from the trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors muscles of 26 dairy workers were used to create muscle activity profiles for the milking tasks common in large-herd dairy parlors. Functional maximum voluntary contractions (fMVC) were collected to normalize the sEMG data for appropriate comparisons. Anthropometric measurements were recorded from each worker.

Results: The biceps brachii had the highest muscle activity (14.58% fMVC) of the upper limb muscles measured, exceeding previously established recommendations for working tasks. The anterior deltoid had the least amount of activity, while the upper trapezius had the least amount of muscular rest during milking work. Worker stature was negatively associated with upper limb muscle activity.

Conclusion: Milking tasks in large-herd dairy parlors have significant effects on the upper limb muscle activity of workers. The muscle activity of biceps brachii during normal work tasks exceeded the recommended safe limit. Wrist flexors and upper trapezius approached the recommended limit. The study findings suggest that milking tasks in large-herd dairies may increase the worker's risk for developing musculoskeletal symptoms and possibly musculoskeletal disorders.

Keywords: ergonomics, dairy workers, milking, surface electromyography, work-related musculoskeletal disorders

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INTRODUCTION

Dairy farming is one of the oldest agriculture practices in human history (1). Throughout the last 200 years, modern milking operations have drastically changed from their ancestral counterparts in both size and technology used. What were once considered large farms of 20–25 cows using manual foot-powered Mehring milking machines in the 1890s have become operations of 1500+ cows with parlor milking systems (2). Advances in milking technology combined with economics of scale have led to the industrialization of the modern dairy farm. Large- and mega-herd dairy farms in the U.S. consist of 5% of American dairy operations but produce 65% of the domestic milk (3). Despite the economic advantages of large-herd milking operations, the industrialization of dairy processes has led to highly repetitive and physical work demands, which have been associated with the development of musculoskeletal disorders (MSDs) (4, 5).

To date, occupational health research within the dairy industry has primarily been focused on workers employed on small-herd farms (6–13). Occupational health researchers have concluded that milking tasks on small-herd farms require high muscular load (11, 13), consist of highly repetitive motions (6, 12), are physically demanding (14), and are associated with musculoskeletal symptoms (MSS) (8, 15) and MSDs (6, 11, 15). The same occupational risk factors identified in small-herd dairies can be expected in large-herd dairy farms; perhaps, to an even greater extent since they require employees to perform the same highly repetitive milking tasks for 812 h per work shift, 6–7 days a week. Researchers have suggested that work performed with large-herd parlor systems increase the risk of injury (16, 17). Yet, industrialized operations have not been well-studied and relatively little is known about the precise muscle loads, duration of muscle use, and muscle fatigue among the parlor workers.

The primary aim of the present cross-sectional research study was to quantify upper limb muscle activity of workers performing milking tasks in large-herd dairies. A secondary aim was to investigate associations between anthropometric variables and surface electromyography (sEMG) activity recorded during milking tasks. Surface EMG from the trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors muscles was used to create muscle activity profiles for the combination of milking tasks performed in large-herd dairies. This is the first published study that has quantified muscle activity with sEMG of the upper limb at large-herd U.S. dairy operations.

MATERIALS AND METHODS

Participants

Based on sample size calculations (see Statistical Analyses) and oversampling, we intended to recruit up to 30 workers (26 based on power calculations plus oversampling of 4). Dairy parlor workers were recruited from a pool of 36 dairy parlor workers employed at six large-herd dairy farms in Colorado, USA. Inclusion criteria included 18 years and older, free from any current musculoskeletal pain, and at least 6 months of experience working in a dairy parlor. Recruitment of workers was conducted through verbal announcements at the dairy and by paper notices posted in the indoor lunch area of the dairies. Subjects were compensated $30 for their participation. This study was carried out in accordance with the recommendations of Institutional Review Board of the investigator's university, with written informed consent from all subjects. All subjects (including dairy company owners) gave written informed consent in accordance with the Declaration of Helsinki.

Data Collection Procedures

Several anthropometric measurements were recorded from each worker as illustrated in **Figure 1**. These measurements included functional overhead reach, standing height, standing height wearing boots, eye level and shoulder acromial height, forward functional reach, waist height, and grip breadth, which was measured as the circumference between the thumb and middle finger.

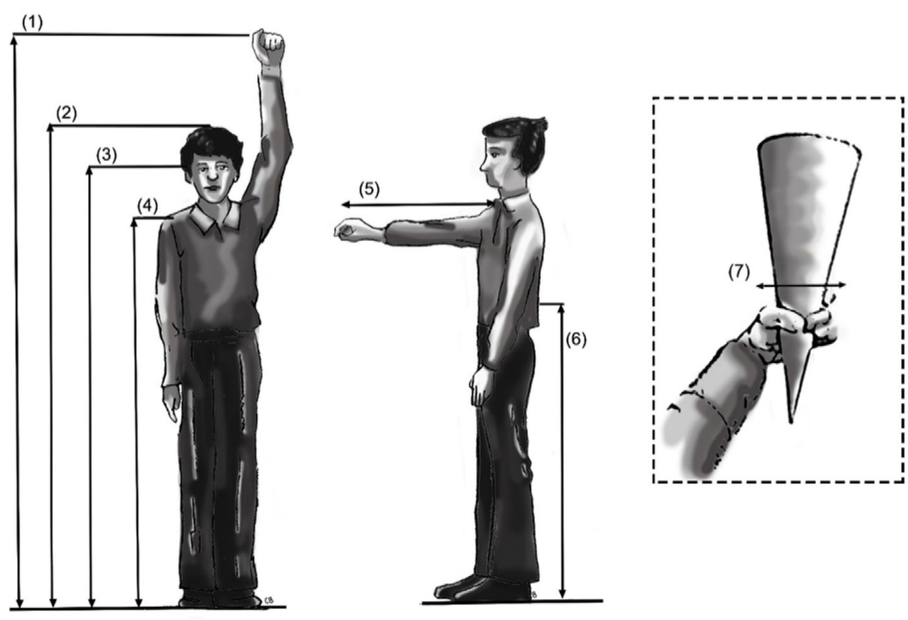

FIGURE 1 | **Anthropometric measurements recorded (1) functional overhead reach, (2) standing height, (3) eye level height, (4) shoulder acromial height, (5) functional forward reach, (6) waist height, and (7) grip breadth**.

Surface electromyography with a sampling frequency of 1000 Hz using Biometrics DataLOG (Biometrics, England) was collected from the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors. Bipolar electrodes (Biometrics, Ltd.) were attached to skin with double-sided tape directly over the midsection of the muscle belly of the dominant arm. The appropriate sEMG electrode placement was determined by palpitation while functional movements of the upper limb were performed (18). Real-time streaming of sEMG was visually examined to assure that muscle activity coincided with appropriate functional movements (e.g., raising and lowering the upper limb to check activation of the anterior deltoid).

Functional Maximum Voluntary Contraction Procedures

Functional maximum voluntary contractions (fMVC) were collected to normalize sEMG data for appropriate comparison. Before commencing fMVC, a 30-s baseline resting sEMG signal was collected to establish a minimum resting muscle activity. Three fMVC trials were administered for each subject for each muscle group. Participants were instructed to ramp up to a maximum muscular effort, hold for 4 s. After each trial, a maximum was calculated using the middle 3 s of the root mean square (RMS)-processed sEMG trial data. Covariance was calculated using the mean and SD. If the covariance exceeded 15% for the three fMVC trials, additional trials were conducted up to a total of five.

Functional MVCs for the anterior deltoid and upper trapezius were collected using procedures established by Boettcher et al. (19). Wrist flexor and extensor fMVCs were obtained simultaneously through a co-contraction while gripping a hand dynamometer (Biometrics G100, England). Participants were instructed to maintain a maximum power grip on the dynamometer while maintaining the elbow in 90° of flexion. Functional MVCs for the biceps brachii were recorded simultaneously during the MVC procedures for the wrist flexor and extensors.

Milking Tasks

All subjects completed the five distinct milking tasks common in large-herd dairy parlors, as follows: (1) pre-dipping the teats into a sanitizing solution, (2) stripping each teat to stimulate milk letdown, (3) wiping the teats to remove the sanitizing solution, (4) attaching the milking cluster, and (5) post-dipping the teats with a sanitizing solution. Typically, pre-dipping, wiping, and post-dipping were completed with one arm, while stripping and attaching required both arms/hands. With tasks that could be completed using one arm, workers were instructed to use the arm instrumented with sEMG (same side as dominant hand). To develop muscle activity profiles, it was necessary to precisely determine when milking tasks began and ended. This was accomplished using a digital-event-marker that was triggered within the sEMG stream at the start of the data collection period. Data were collected on each worker for the duration of time it took to completely milk one pen of cows (typically 225–275 cows), which ranged from a 45- to 90-min period. During the data collection period, there were no breaks (bathroom, smoking, lunch, etc.) and little time, if any, for other tasks. If other tasks were performed, they were related to the milking tasks, such as refilling the towel dispenser, hosing off the stall with water, or refilling the supply of teat cleansing solution. Any short periods of rest, as well as periods involving other minor work tasks, were collected in the sEMG sample. The authors estimate that the other minor milking tasks involved less than 5% of the workers time during the actual data collection period.

Muscle Activity Profiles

Following the normalization of all sEMG data using functional MVCs, muscle activity profiles were developed. Functional MVC data were processed with 100 ms moving average as recommended in the literature (20). The maximum value determined from this processing procedure was used to normalize the sEMG data collected during the milking tasks. The sEMG data were normalized using the instantaneous maximum value determined from the highest 100 ms average. Normalization was completed using an arithmetic process, where %*MVC* is normalized muscle activity, *sEMG* represents processed sEMG data, *fMax* represents instantaneous maximum value from fMVC trials, and *Rest* represents the minimum value from the 30-s baseline.

$$\%\text{MVC} = \frac{(\text{sEMG} - \text{Rest})}{(\text{fMax} - \text{Rest})} \quad (1)$$

Temporal analysis of sEMG data was accomplished through the RMS processing technique (21). A graphic user interface was created using MATLAB 7.10.0 (Mathworks, Natick, MA, USA) to process sEMG data and obtain mean RMS values. Amplitude probability distribution function (APDF) was determined for the 10th, 50th, and 90th percentile (22) using custom software (21) developed in LabVIEW (National Instruments, Austin, TX, USA). Percentage muscular rest (%MR) of sEMG was determined with a maximum threshold of 0.5% MVC and a minimum gap duration of 0.25 s (23). The same LabVIEW custom software (21) was used to determine %MR values. Muscle activity profiles were constructed for each muscle with normalized muscle activity expressed as RMS, ADPF, and %MR. The muscle activity data were averaged across subjects for each muscle providing an estimate of the overall muscle activity and recovery experienced by parlor workers during the five milking tasks.

Statistical Analyses

All statistical analyses were administered using SAS 9.3 (SAS Institute Inc., Cary, NC, USA). Sample size was determined from power calculations using a conventional alpha level of 0.05, a beta level of 0.20, representing 80% power, and effect magnitudes based on previously published EMG data from field (6, 12) and laboratory-based (24) studies. Descriptive statistics for subjects and muscle activity profiles were constructed. Muscle profiles were examined using a random block 26 × 5 ANOVA (Subject × Muscle) with a Tukey Honest Significant Difference *post hoc* adjustment to determine significant differences in the RMS, APDF, and %MR variables. Correlations among these three measures were also examined. Statistical significance was set at $p < 0.05$ *a priori*.

RESULTS

Participants

Twenty-nine dairy parlor workers out of a possible 36 met the inclusion criteria and agreed to participate in the study. Two workers in the study were excluded from the data analysis due to equipment malfunctions that resulted in incomplete data. An additional subject did not show up on their scheduled day of sEMG collection and did not complete the study. Of the 26 participants whose data were analyzed, 25 were males and one was female. Workers were 18–53 years of age (mean = 29.7 ± 9.8 years) with work experience in cow dairies from 6 months to 20 years (mean = 3.4 ± 4.8 years). All participants had experience in the common milking tasks of pre-dipping, stripping, wiping, attaching milking clusters, and post dipping. The participants had an average functional stature of 166.4 cm (±9.3), an average forward reach of 61.3 cm (±3.5), and an average BMI of 26.4 (±4.2). Twenty-five of the participants were right-hand dominant, and one was left-hand dominant. Fifteen indicated at least some high school education and remaining participants indicated eighth grade or lower as their education level. All workers self-identified as Latino/a, with the majority from Mexico ($N = 10$) and Guatemala ($N = 10$). Latino workers account for the majority of the workforce in Colorado large-herd dairy parlors, as indicated by Patil et al. (14).

Muscle Activity Profiles

Muscle activity profile data are outlined for the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors (**Table 1**). Additionally, muscle activity profiles of each muscle were constructed based on the APDF and are illustrated in **Figures 2–6**.

The ANOVA of the mean RMS indicated significant ($p = 0.001$) differences between anterior deltoid and biceps brachii (**Table 2**) with the biceps brachii having twice the mean activity of the anterior deltoid. Additionally, mean EMG activity for the wrist flexors were significantly ($p = 0.05$) less than biceps brachii. There were no other significant differences in the RMS muscle activity profiles.

Results of the normalized 50th percentile APDF ANOVA (**Table 3**) indicated that the anterior deltoid had significantly less muscle activity than biceps brachii ($p < 0.001$), upper trapezius ($p = 0.03$), and wrist extensors ($p = 0.01$), but not less than wrist flexors ($p > 0.05$) muscles during the milking tasks. Biceps brachii had significantly more muscle activity than wrist flexors ($p = 0.003$) and upper trapezius ($p = 0.05$).

The ANOVA for normalized %MR (**Table 4**) indicated that the anterior deltoid had significantly greater rest than biceps brachii ($p < 0.001$), upper trapezius ($p < 0.001$), wrist extensors ($p = 0.003$), but not wrist flexors ($p = 0.11$) muscles. The upper trapezius had significantly ($p = 0.02$) less rest than wrist flexors.

Anthropometric Analysis

Functional stature, shoulder acromial height, functional forward reach, hand grip breadth, BMI, and age were examined to determine if these anthropometric variables would be correlated with normalized mean RMS activity, APDF, and %MR. Combining data for all the muscles revealed significant negative correlations between mean RMS activity with functional stature ($R = -0.22$, $p = 0.01$) and mean RMS activity with shoulder acromial height ($R = -0.20$, $p = 0.02$). Thus, as worker's height decreased, upper limb muscle activity tended to increase. Normalized APDF had similar statistically significant negative correlations with functional stature ($R = -0.19$, $p = 0.01$) and shoulder acromial height ($R = -0.17$, $p = 0.01$). Normalized %MR had significant positive correlations with functional stature ($R = 0.23$, $p = 0.01$) and shoulder acromial height ($R = 0.22$, $p = 0.01$). There were no other significant correlations between anthropometric variables and normalized RMS, APDF, and %MR. The correlations between functional stature and muscle activity measures indicated that shorter workers had more upper limb muscle activity and less muscular rest compared to taller workers.

Functional stature was examined to determine if there was an interaction effect with specific muscles for normalized mean RMS activity and %APDF. The normalized RMS ANOVA revealed no significant interaction between muscle and functional stature ($p = 0.38$). However, the main effects indicated that functional stature was significantly ($p = 0.009$) associated with mean RMS activity. The normalized APDF ANOVA also revealed no significant ($p = 0.49$) interaction between muscle and functional stature. Additionally, the main effects revealed functional stature as significantly ($p = 0.02$) associated with APDF.

Functional stature was also assessed to determine if an interaction occurred with muscle type for the normalized %MR. There was no statistically significant interaction between muscle type and functional stature; however, the interaction approached significance ($p = 0.07$). This finding suggests an interaction

TABLE 1 | Activity profiles of upper extremity muscles studied.

	Upper trapezius Mean (SD)	Anterior deltoid Mean (SD)	Biceps brachii Mean (SD)	Wrist flexors Mean (SD)	Wrist extensors Mean (SD)
10th percentile APDF	1.13 (2.07)	0.15 (0.39)	1.21 (2.23)	0.40 (0.60)	0.55 (0.92)
50th percentile APDF	9.28 (6.61)	3.49 (3.71)	14.58 (11.5)	7.41 (5.10)	9.75 (5.70)
90th percentile APDF	31.43 (21.05)	43.37 (36.26)	51.23 (38.86)	36.75 (21.41)	44.11 (31.13)
Mean RMS %fMVC	13.58 (9.19)	9.79 (3.71)	19.44 (13.87)	12.73 (6.24)	14.02 (7.73)
%MR	6.64 (7.24)	22.77 (12.75)	9.45 (7.73)	13.58 (8.25)	13.16 (6.69)

RMS, root mean square; APDF, amplitude probability distribution function; %fMVC, percent functional maximum voluntary contraction; %MR, percent muscular rest.

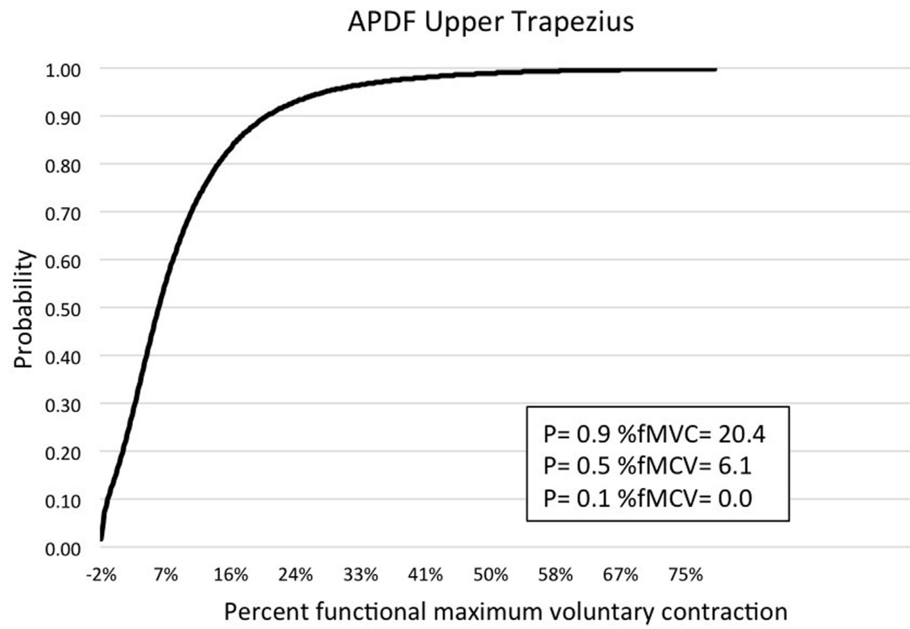

FIGURE 2 | **Graphic representation of typical APDF of the upper trapezius**.

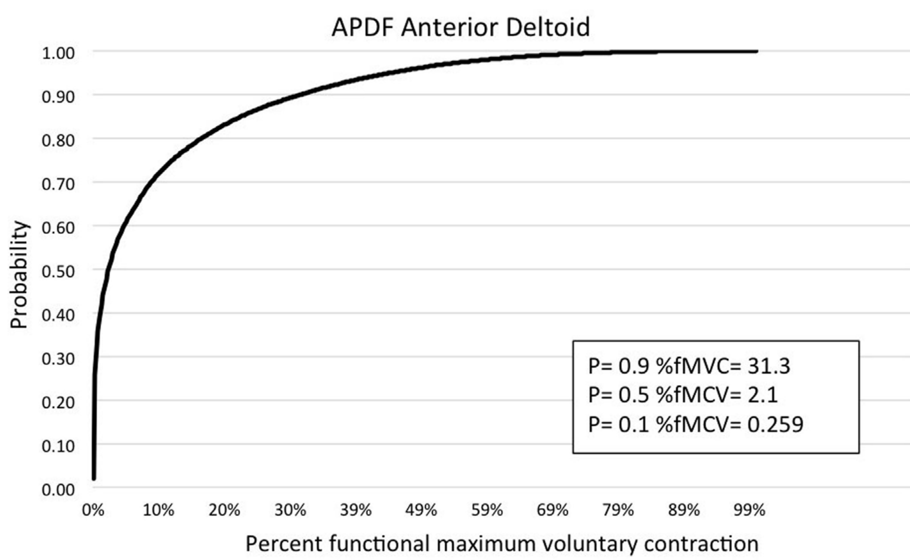

FIGURE 3 | **Graphic representation of typical APDF of the anterior deltoid**.

between muscle type and functional stature for %MR, which may be revealed in studies with larger sample sizes.

DISCUSSION

The aim of this research was to quantify upper limb muscle activity of workers performing milking tasks in large-herd dairies. Normalized mean RMS sEMG activity was significantly different between the biceps brachii and anterior deltoid muscles, which had the highest and lowest values, respectively. Normalized 50th percentile APDF revealed nearly identical results with the anterior deltoid displaying the least amount of muscle activity and biceps brachii displaying the highest mean muscle activity. These results were contrary to our initial hypothesis that the anterior deltoid would have the greatest amount of muscle activity during milking tasks. There were several possible explanations that could account for the anterior deltoid's relatively low muscle activity during milking tasks. First, the middle deltoid also contributes

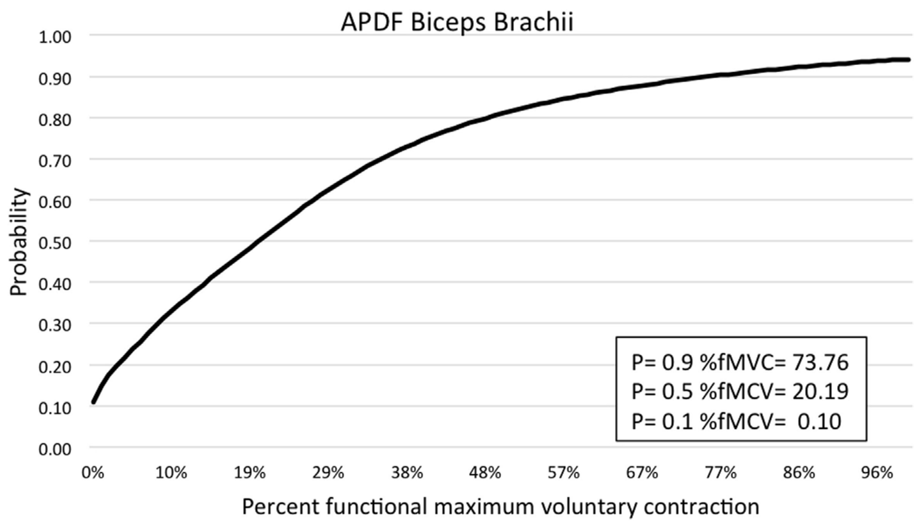

FIGURE 4 | **Graphic representation of typical APDF of the biceps brachii**.

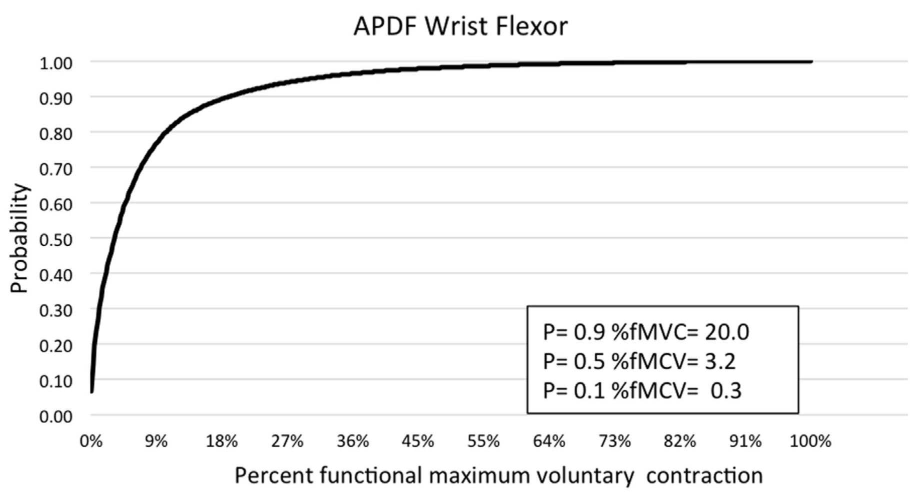

FIGURE 5 | **Graphic representation of typical APDF of the wrist flexors in the forearm**.

to shoulder elevation but was not measured in the present study. Second, tasks performed near the worker's shoulder height can be accomplished with minimal shoulder flexion through primarily elbow flexion if the task is performed close to the worker (minimal horizontal distance between worker and task). Additionally, the anterior deltoid may have been assisted in shoulder flexion by the action of the biceps brachii that is also active in shoulder flexion. Lastly, although the present study did not examine the effects of fatigue, it is plausible that over time the workers' anterior deltoid adapted to increasing work demands placed on the shoulder joint by increasing biceps activity.

The anterior deltoid was revealed to have the most muscular rest, while the upper trapezius and biceps brachii had the least. The differences in %MR between the anterior deltoid and the trapezius and biceps may have been related to work activities other than milking tasks during the data collection period, which were not distinguished in this study. Observationally, brief breaks existed between milking groups of cows being milked within herringbone and parallel parlor configurations. Depending on the dairy and parlor configuration, some workers rested when one group of cows was exiting and the next group was entering the parlor. In some dairies, the time between milking groups of cows consisted of workers rinsing floors, hosing down stalls, folding towels, and checking equipment. Regardless, workers generally kept their shoulders in near neutral positions during non-milking tasks. Most of the non-milking tasks were accomplished using elbow flexion (biceps activity) for elevating the hand and tools while minimizing anterior deltoid activity. This is one possible

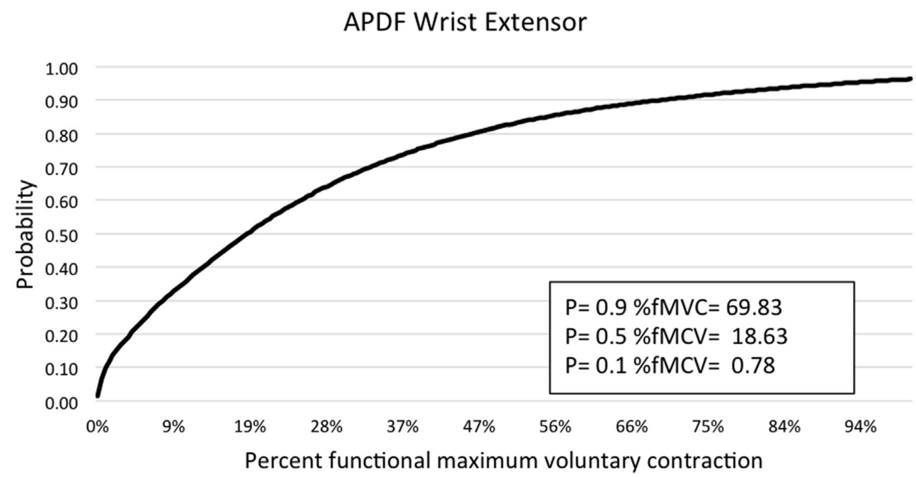

FIGURE 6 | **Graphic representation of typical APDF of the wrist extensors in the forearm**.

TABLE 2 | ANOVA of mean RMS muscle activity for muscle pairs.

Muscle	%fMVC mean (SD)	Delta	Adjusted *p*-value
Anterior deltoid vs. biceps brachii	9.79 (3.71) vs. 19.44 (13.87)	9.70	0.001
Wrist flexors vs. biceps brachii	12.73 (6.24) vs. 19.44 (13.87)	6.71	0.05

RMS, root mean square; %MR; percent muscular rest; %fMVC, percent functional maximum voluntary contraction.

TABLE 3 | ANOVA of 50th percentile APDF for muscle pairs.

Muscle	%fMVC mean (SD)	Delta	Adjusted *p*-value
Anterior deltoid vs. biceps brachii	3.49 (3.71) vs. 14.58 (11.5)	11.08	<0.0001
Anterior deltoid vs. upper trapezius	3.49 (3.71) vs. 9.28 (6.61)	5.78	0.03
Anterior deltoid vs. wrist extensors	3.49 (3.71) vs. 9.75 (5.70)	6.25	0.01
Biceps brachii vs. wrist flexors	14.58 (11.5) vs. 7.41 (5.10)	7.18	0.003
Biceps brachii vs. upper trapezius	14.58 (11.5) vs. 9.28 (6.61)	5.30	0.05

APDF, amplitude probability distribution function; %fMVC, percent functional maximum voluntary contraction.

explanation for the differences recorded in muscle usage between the anterior deltoid and biceps brachii. The relatively low level of %MR recorded for the upper trapezius may have been due to the muscle being used often for elevation and upward rotation of the shoulder (25) during reaching activities. The upper trapezius would also be active when the arm is in a relatively neutral position, while the hands are used for carrying equipment or operating tools. Dairy tasks have been characterized as physically strenuous and demanding for the upper extremity (11, 15, 26–28), which can result in increased muscular tension in the upper trapezius.

TABLE 4 | ANOVA of %MR for muscle pairs.

Muscle	%fMVC mean (SD)	Delta	Adjusted *p*-value
Anterior deltoid vs. biceps brachii	22.77 (12.75) vs. 9.45 (7.73)	13.32	<0.0001
Anterior deltoid vs. upper trapezius	22.77 (12.75) vs. 6.64 (7.24)	16.13	<0.0001
Anterior deltoid vs. wrist extensors	22.77 (12.75) vs. 13.16 (6.69)	9.61	0.003
Upper trapezius vs. wrist flexors	6.64 (7.24) vs. 13.58 (8.25)	6.94	0.02

%MR; percent muscular rest; %fMVC, percent functional maximum voluntary contraction.

Stål et al. (11) examined muscular load of the biceps, along with the flexor and extensor muscles of the forearms with sEMG within loose housing and tethering milking systems. The researchers used APDF and %MR to assess muscle activity. Although researchers did not statistically compare muscle activity, the authors indicated that visual examination of the sEMG signals revealed possible differences between muscles. The APDF of the biceps appeared to have nearly half the muscular activity as the forearm extensors and flexors, but there was no notable difference between muscles when viewing %MR. Pinzke et al. (6) also examined the muscular loads of biceps and forearm flexors associated with drying, pre-milking, and attaching in a loose-housing milking system. The authors reported that the biceps also had nearly half the activity as compared to the forearm fingers and flexors for each task except attachment. But, unlike Stål et al. (11), they reported that the biceps exhibited greater muscular rest. Although both previously mentioned studies employed the same methodology to determine muscular rest and APDF, Pinzke et al. (6) investigated each of the milking tasks separately, while Stål et al. (11), like the present study, examined the average muscle activity for the entire milking period.

Amplitude probability distribution function has been commonly used to assess the risk of developing MSDs due to work overload (22). Recommended muscle activity levels to reduce the risk of MSDs were developed for static work (10th percentile APDF), mean activity (50th percentile APDF), and maximum activity (90th percentile APDF). Static APDF activity is recommended to be below 2% MVC and to never exceed 5% MVC. The recommended level for the mean APDF activity is less than 10% MVC and to never exceed 14%. The recommendation for maximum APDF activity is less than 50% MVC and to never exceed 70% MVC (29). In the present study, biceps brachii had the mean APDF value at 14.58% MVC, exceeding the recommended high limit of 14%. The mean APDF for the wrist extensors and upper trapezius were below the 10% threshold at 9.75 and 9.28% MVC, respectively. The values presented in this present study differ from those determined by other researchers. Stål et al. (12) evaluated biceps brachii and wrist flexors activity during assisted and unassisted cluster attachment tasks. The researchers determined APDF for the 50th percentile of wrist flexor activity was 13% MVC and 6.1% MVC for biceps activity during milking cluster attachment. Another research group examining muscle activity at the 50th percentile APDF for milking tasks determined that biceps brachii activity ranged from 5.9 to 9.8% MVC, while wrist flexors activity ranged from 7.5 to 27% MVC (6). However, both studies above examined sEMG by each of the specific milking tasks. As in the present study, Stål et al. (11) examined sEMG of the upper limb for all milking tasks combined. They determined the 50th percentile APDF for the biceps brachii (3.9% MVC), wrist flexors (7.4% MVC), and extensors (8.5% MVC). Wrist flexor and extensor activity levels in the study by Stål et al. (11) were comparable to those reported in the present study. However, for biceps brachii at the 50th percentile APDF, the Stål group reported 3.9 vs. 14.58% MVC in the present study. This difference could be related to the type of work activity demands conducted in small- vs. large-herd dairies. Additionally, the majority of workers in the Stål et al. (11) study were females, as opposed to the majority being males in the present study.

Although there are no field studies that have examined muscle activity of the upper limb in large-herd dairies, several researchers (22, 24, 29, 30) recreated large-herd dairy milking tasks in a laboratory setting to conduct in-depth simulations of cluster attachments to investigate the effects of cluster weight reduction. Those researchers determined through sEMG that the attachment of a common 2.4 kg milking cluster imposed a considerable muscular load on upper limb muscles (22, 24). Reducing the mass of the milking cluster to 1.4 kg decreased mean muscle activity up to 20% (24). The muscle activity was not calculated using APDF but rather using the normalized integrated sEMG similar to RMS processing. For most upper limb muscles, the sEMG results during milking tasks reported by Jakob et al. (24) were comparable to our sEMG RMS processed findings (**Table 1**) with the exception of the anterior deltoid. The mean RMS anterior deltoid activity in the present study (9.738% MVC) was much lower than that reported by Jakob et al. (24) at 23.39% MVC. However, that difference is likely explained by the different methods and tasks examined. Jakob et al. (24) examined the attachment of the milking cluster, a task that requires worker's arms at or above shoulder height in order to complete the task, while the muscle activity measurements in the present study comprised all milking tasks performed in the dairy parlor.

There is evidence in the literature of a relationship between lack of muscular rest and the development of shoulder disorders among occupational tasks involving the upper trapezius. Veiersted et al. (31) examined the relationship between muscle usage (activity and rest) and the development of trapezius myalgia through sEMG analysis. Data collection sessions comprised 10 min of sEMG sampling, while the subjects worked at their habitual work rhythm. The 50th and 90th percentiles of the APDF were used to describe muscular load, and muscular rest was defined by activity gaps under 0.5% MVC and durations of 0.2 s. The authors reported that as muscular rest increased by an additional gap per minute, the subjects' risk of developing work-related MSDs decreased 6%. Subjects who did not experience MSD had gap rates greater than 10.8 gaps per minute or roughly 4% muscular rest. Hansson et al. (23) revisited the use of %MR to examine the sensitivity of the trapezius when comparing different work tasks by hospital cleaners and office workers. For repetitive work tasks, the sEMG activity at the 50th percentile APDF ranged from 3.6 to 8.1% APDF for the trapezius, less than those found for large-herd dairy parlor tasks. Muscular rest for the repetitive work tasks ranged from 1.1 to 13.4% of total work time. In the present study, muscular rest for upper trapezius during milking tasks was 6.6%, which was within the range presented for repetitive office and cleaning work tasks. Hansson et al. (23) found that %MR was a more precise measure than various APDF percentiles of the trapezius for comparison of work tasks. Although the development of trapezius myalgia has not been specifically evaluated in the dairy industry, the risk of such a disorder is likely present, as dairy work has some of the same movement and load characteristics as repetitive manufacturing tasks (13). Dairy parlor tasks work have been associated with MSS and WRMSDs (5, 8, 11, 14, 15). For example, in large-herd U.S. dairies, almost three-fourths of the milking workers had MSS in some anatomical region (8). Additionally, Kolstrup (15) used a modified version of the Standard Nordic Questionnaire and reported a high prevalence of MSDs among workers in shoulders, hands/wrist, and low back among workers in small-herd Swedish dairies. Patil et al. (14) examined the prevalence of carpal tunnel syndrome among workers in large-herd dairies and concluded that the prevalence of carpal tunnel syndrome was significantly higher among workers performing milking tasks than those in other areas of the dairy. Although the present study did not find that overall wrist flexors and extensors sEMG activity was beyond recommended levels for the 10th, 50th, and 90th APDF percentiles, wrist extensor activity was approaching the maximum threshold for 50th APDF and 90th APDF percentiles. It may be possible that sEMG activity associated with a specific milking task, rather than a variety of milking tasks (as in the present study), would reveal wrist flexor and extensor muscle activity beyond the recommended APDF thresholds and increasing risk for developing a WRMSD (e.g., carpal tunnel syndrome).

Limitations

Surface EMG represents a fairly non-invasive source of information on the state of skeletal muscle activity. However, the application of sEMG in occupational field studies has limitations due to inherent problems associated with sEMG. Some of the variables that may affect the sEMG signal other than the actual muscle activity include electrode configuration, electrode placement and orientation, procedures for determining a functional MVC, cross talk from other muscles, movement artifact, muscle movement under the surface of the electrode, tissue impedance, and signal processing. It is important to emphasize that the muscle activity reported in the present study represents a combination of all five major milking tasks described as well as other minor tasks associated with the milking process. This study was limited to overall muscle activity of the upper limb and not focused on specific milking tasks. Additionally, the results of this study are limited to the workers at large-herd dairies in Colorado, USA, and caution should be exercised with extending these results to other populations of dairy parlor workers.

CONCLUSION

Milking tasks in a large-herd dairy parlor have significant effects on upper limb muscle activity of workers. The muscle activity of biceps brachii measured in the present study exceeded the recommended ≤10% MVC for the 50th percentile APDF. Wrist flexors and upper trapezius were approaching the recommended ≤10% MVC threshold. The study findings suggest that milking tasks in large-herd dairies may increase the worker's risk for developing MSS and possibly MSDs.

Although this investigation represents novel work on upper limb muscle activity among workers performing milking tasks in large-herd industrialized dairies, additional research is needed to for targeted interventions, which could reduce pain MSDs. Future studies should focus on determining how each of the specific milking tasks contributes to upper limb muscle load as well as the kinematics of the upper limb during the work tasks. Other possible future research includes the effects of muscular fatigue from dairy parlor work and comparison of the present study findings to small- and medium-sized herd dairies.

AUTHOR CONTRIBUTIONS

All authors (AM, FM, CB, JR) have (1) contributed substantially to the conception or design of the work and/or the acquisition, analysis, or interpretation of the data for the work, (2) participated in drafting the work or revising it critically for important intellectual content, (3) approved the final version to be published, and (4) agreed 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. JR was the local principal investigator and lead academic for this part of the grant award. He led the design of the study, providing expertise in sEMG and occupational biomechanics, and made a significant contribution to both the interpretation of data and the writing of the final paper. AM was the doctoral researcher who was significantly involved in the design of the study, led the collection and analysis of data, significantly contributed to the interpretation of data, and wrote the first draft of the paper. FM was the doctoral researcher that contributed to the design, data collection, data analysis, and also the editing of the paper. CB was the student researcher contributing to the interpretation of data and co-editing the various drafts as well as the final paper.

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Comparison of Upper Limb Muscle Activity among Workers in Large-Herd U.S. and Small-Herd Italian Dairies

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Objectives: Commercial cow milking tasks, regardless of dairy size, have been documented in many regions of the world as strenuous work requiring high muscular effort, awkward positions, and task repetition. Large-herd dairies are common in the U.S., while Europe historically has mostly small-herd dairies. The objective of this study was to compare the upper limb muscle activity during milking tasks between workers at large-herd U.S. dairies and small-herd Italian dairies. This is the first international study directly comparing upper limb muscle activity among dairy workers from different countries using identical methods.

Methods: Data were collected at 6 large-herd dairies in the U.S. region of Colorado and at 21 small-herd Italian dairies in the Lombardy region. Surface electromyography (sEMG) from the trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors muscles was recorded from all participating workers ($N = 65$). Electromyography data were normalized to functional maximum voluntary contractions. Anthropometric measurements were also recorded.

Results: Upper limb muscle activity was generally greater among workers in the large-herd U.S. dairies compared with small-herd Italian dairies. The amount of muscular rest as a percent of the work time was significantly greater among large-herd U.S. dairy workers.

Conclusion: The differences revealed in sEMG and percent muscular rest among workers from the U.S. and Italy are likely due in part to differences in work processes adopted by fast-paced industrialized large-herd dairies compared with the slower, but sustained work processes performed at small-herd dairies.

Keywords: milking, surface electromyography, ergonomic, dairy work, musculoskeletal disorders

INTRODUCTION

The work of milking dairy cows has been performed throughout the world for thousands of years (1). Although farms in some developing countries continue traditional methods of manual hand milking, the majority of the world's dairy industry has modernized in the past 50 years from vacuum bucket milking to advanced dairy parlor designs (2) that include automation and precision dairy farming systems. According to Schroeder "technology and increased access to data are enabling dairy farmers to make smarter day-to-day decisions to improve cow health, production, and on-farm efficiencies" (3). Many of the same technological and process changes that have driven efficiency on farms have led to less than ideal ergonomic design within the dairy parlor. Poor system and task design can increase the worker's risk of developing occupationally related musculoskeletal symptoms (MSSs) and musculoskeletal disorders (MSDs).

Occupationally related MSSs and MSDs often develop from work tasks characterized by excessive exposure to work tasks involving forceful muscle exertions, high number of repetitive motions, and awkward body postures (4, 5). Many of today's milking systems expose the dairy parlor workers to the same risk factors (high muscle loads, repetition, and awkward postures) for MSSs and MSDs (6–10). Regardless of milking stall design, herd size of dairy operation, or geographical region, from an ergonomics perspective, milking tasks have been documented as involving strenuous work with high muscular loads, high repetition and awkward postures on the upper limb (6, 7, 9–12).

Unfortunately, there are very few international studies comparing occupational risk factors and health outcomes related to dairy work between countries. Recently, Kolstrup and Jakob compared the prevalence of MSSs and MSDs between groups of dairy workers from Sweden and Germany (10). International studies comparing upper limb muscle activity of workers performing milking tasks between any two countries have not been reported previously. Although herd sizes are generally larger in U.S. dairies as compared with Italian, both countries predominately use loose housing systems performed in milking parlors (herringbone, parallel, or rotary configurations), which involve very similar milking processes and work tasks.

Due to the consistently high prevalence of injuries among dairy workers globally, it is prudent for researchers to pool resources and expertise to study and address this international occupational challenge. Thus, the objective of this study was to compare the upper limb muscle activity among workers performing milking tasks in large-herd U.S. dairies with workers in small-herd Italian dairies. The research team conducted this study with the same equipment, methods, and data processing techniques at dairies in the U.S. state of Colorado and the Lombardy region of Italy.

Dairy Industry Status and Profile in U.S.

Dairy production is a significant component of the U.S. economy and is second only to beef among all livestock industries, with about 138,000 people employed annually in the U.S. (13). The dairy workforce force consists predominantly of hired labor, and estimates indicate that 57,000 are foreign born, with the main ethnic demographic being Latino (13, 14). According to the U.S. Department of Agriculture, the dairy sector in 2015 accounted for 43,584 farms and over 9.3 million dairy cows that collectively produced 94.6 million metric tons of milk (15), which make U.S. the second largest world cow milk producer after the European Union.

Among all U.S. dairy operations (family as well as corporate-owned and operated), the mean herd size is 214 cows. Over the last decade, there has been a shift in farm structure from small (<500 cows) to large (1,000–2,000 cows) and mega-herd (2,000+ cows) dairies (16, 17). Approximately half of the total number of milking cows in the U.S. are raised on large farms with at least 1,000 heads, while smaller farms account only for 17% of total animals (18). As herd size increases, dairy operations become remarkably different than the family farm in terms of management and employment practices as well as the organization of work processes (14). The large- and mega-herd dairy operations are highly mechanized, automated, and typically require one worker for every 80–100 cows, excluding the cropping operations. The fast-paced mechanized milking processes at mega-herd dairies require high task specificity with workers focusing on fewer components of the total milking system. USDA statistics for Colorado indicate the presence of 148,000 cows and 120 licensed dairy farms, which produced 1,701 million kilograms of milk (15). The mean herd size in Colorado was 1,233 head indicating a high intensity dairy region (15).

Dairy Industry Status and Profile in Italy

In Italy, the dairy industry as a whole (production of all dairy products) is the largest food sector contributing more than 12% to the national food sales. The most recent data from 2016 indicates that there are 35,177 dairy operations and 186 millions cows contributing to a total milk production of more than 11,152 million kilograms per year (19). Italian dairy farms are generally characterized by a very small herd size with 53 cows as the national average and with an average farm production of 315,000 kg of milk per year (19). Italian cow milk production is most concentrated in the northern regions of the country (Lombardy, Emilia-Romagna, Veneto, and Piedmont), which account for 65% of the farms, 77% of the cows, and 75% of the total milk production (20, 21). Lombardy is the region with the highest number of dairy farms (17% of the national value), which raise more than one-third of the Italian dairy cows producing 44% of the Italian milk with an average yield over 9,152 kg/year (22, 23). Due to the significant reduction of dairy farms, average herd sizes have almost doubled since the 1990s. However, in 2011, 90% of Italian dairy farms still had less than 100 cows, while the number of operations with at least 1,000 cows was only 14 (23).

Italian dairy farming is still principally based on family managed operations that employ more than 100,000 workers throughout the country (24). Immigrants from India and Pakistan are a significant and growing part of dairy workforce, particularly, in the Lombardy region (25–27). The majority of dairy farms milk cows twice or three times a day, with herringbone and parallel milking parlors the most common.

METHODS AND PROCEDURES

Participants

Six large-herd dairies in the U.S. state of Colorado that had an average dairy herd size of 2,200 head, and 21 small-herd dairies in the Lombardy region of Italy with an average herd size of 350 head participated in the study. A sampling method of convenience rather than randomization was employed. Only subjects aged 18 years or older and free from current musculoskeletal pain at the time of data collection were recruited for participation. An additional eligibility criterion for the Italian sample was not to have had any wrist surgery in the previous 3 years. Participant recruitment was conducted through verbal announcements by supervisors and owners at the dairy and by printed notices posted in the break rooms at the dairies. In the U.S., the research team had working relationships with six dairies, all of who participated. Of the 36 possible parlor workers at these dairies, 28 participated (26 used in data analyses), while the other workers were not available at the data collection time ($N = 1$), not interested ($N = 6$), or met exclusion criteria ($N = 1$). In Italy, 21 out of 40 dairies contacted and agreed to participate in the study. Of the 45 possible parlor workers at these 21 dairies, 40 participated (39 used in data analyses), while the others were not available at data collection time ($N = 3$) or met exclusion criteria ($N = 2$). Subjects in U.S. were compensated $30 in addition to their normal wage for participation, whereas subjects in Italy received their usual wage only. This study was carried out in accordance with the recommendations of Institutional Review Board of the investigator's universities (Colorado State University and University of Milan) with written informed consent from all subjects. All subjects (including dairy company owners) gave written informed consent in accordance with the Declaration of Helsinki.

Data Collection Procedures

Anthropometric measurements were recorded from all subjects in both the U.S. and Italian research sites, according to methods described by Rodgers (28) and Mixco et al. (29). These measurements included functional overhead reach, functional standing height (wearing shoes), shoulder acromial height, forward functional reach, and grip breadth, which were measured as the circumference between the thumb and middle finger. In both the countries, surface electromyography (sEMG) with a sampling frequency of 1,000 Hz using Biometrics DataLOG (Biometrics, England) was collected from the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors as described in detail previously (29). At the U.S. dairy farms, data were recorded for the length of time it took to completely milk a pen of cows (range of 225–275 cows), approximately 45–90 min. At Italian dairies, sEMG was recorded for at least 60 min but not more than 90 min depending on the number of cows to be milked and worker break times.

Functional maximum voluntary contractions (fMVCs) were recorded to normalize sEMG data of each muscle. Prior to the collection of fMVC data, a 30-s baseline resting sEMG signal was recorded from each muscle of each subject, which establishes a minimum resting muscle activity. At least three fMVC trials were conducted for each subject for each muscle group. After each trial, a maximum muscle contraction value was determined using the middle 3 s of the root mean square (RMS) processed sEMG signal.

Milking Tasks

Workers in the large-herd U.S. and small-herd Italian dairies in this study performed similar milking tasks during the respective data collection periods. All large-herd U.S. dairy workers in this study completed five distinct milking tasks within the dairy parlor. These tasks included (1) pre-dipping (disinfectant solution lifted to or sprayed on the cow teats; see **Figure 1**), (2) stripping (manually milking teats to stimulate milk production), (3) wiping (cleaning and drying teats with cloth), (4) attaching milking cluster to teats (see **Figure 2**), and (5) post-dipping (second disinfectant solution lifted to or sprayed on the teats). Ten out of the 21 Italian dairies studied did not perform the pre-dipping or post-dipping tasks as part of normal their milking procedures. Additionally, in 25% of the U.S. and 80% of Italian dairies, workers performed the stripping and wiping tasks together with one upper limb motion. In both the countries, for tasks that could be completed using either the right or left arm, subjects were instructed to use the

FIGURE 1 | **An Italian dairy worker pre-dipping teat in a rotary parlor.**

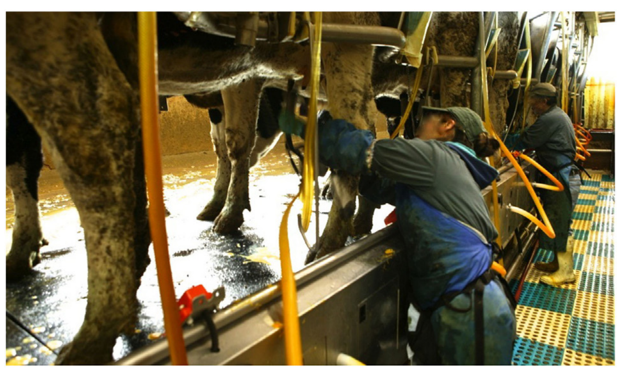

FIGURE 2 | **An American dairy worker attaching milking cluster to cow teats/udder.**

instrumented arm (hand dominant side). In rotary type parlors, subjects were rotated every 15–20 min through three different process points to conduct the different milking operations (tasks 1–2, 3–4, and 5).

Muscle Activity Profiles

After normalization of all sEMG data using fMVCs, muscle activity profiles were developed. Temporal analysis of sEMG data was accomplished through standard RMS processing techniques (30). A graphic user interface was created using MATLAB 7.10.0 (Mathworks, Natick, MA, USA) to process sEMG data and obtain mean RMS values. Amplitude probability distribution functions (APDF) was determined for the 10th, 50th, and 90th percentile (31) using custom software (32) developed in LabVIEW (National Instruments, Austin, TX, USA). Percent muscular rest (%MR) of sEMG was determined with a maximum threshold of 0.5% MVC and a minimum gap duration threshold of 0.25 s (33). Another LabVIEW custom software program (32) was used to determine %MR values. Muscle activity profiles were constructed for each muscle with normalized muscle activity expressed as mean RMS, ADPF, and %MR. The muscle activity data were averaged across workers by country to estimate the overall muscle activity and recovery experienced by parlor workers in the U.S. and Italy during the milking tasks.

Statistical Analysis

This study was a cross-sectional design conducted within the same year in both countries. Statistical analyses were conducted using SAS 9.3 (SAS Institute Inc., Cary, NC, USA). Sample size was determined from power calculations using a conventional alpha level of 0.05, a beta level of 0.20, representing 80% power and effect magnitudes based on previously published EMG data from dairy studies (8, 12). Descriptive statistics for the subjects and muscle activity profiles were computed and summarized. Muscle activity profiles were examined using a random block $2 \times 65 \times 5$ analysis of variance (ANOVA) (dairy location × subject × muscle) with a Tukey Honest Significant difference *post hoc* adjustment to determine differences in the mean RMS, APDF, and %MR variables. Statistically significant interactions between muscle and dairy location (U.S. or Italy) were assessed by examining the simple main effects. Statistically significant differences for anthropometric measures between workers at U.S. and Italian dairies were assessed using Chi squared (χ^2) test and by examining the likelihood ratio test statistic. Statistical significance was set *a priori* at $p < 0.05$.

RESULTS

Participants

A total of 65 workers (26 U.S. and 39 Italy) from 27 dairies (6 U.S. and 21 Italy) participated in the study and had complete data that were used in the analysis of results. All U.S. workers self-identified as Latino with reported countries of origin that included North and Central America (**Figure 3**). The origin of the Italian workers included the continents of Asia, Africa, Middle East, and Europe (**Figure 4**). The χ^2 statistical tests on

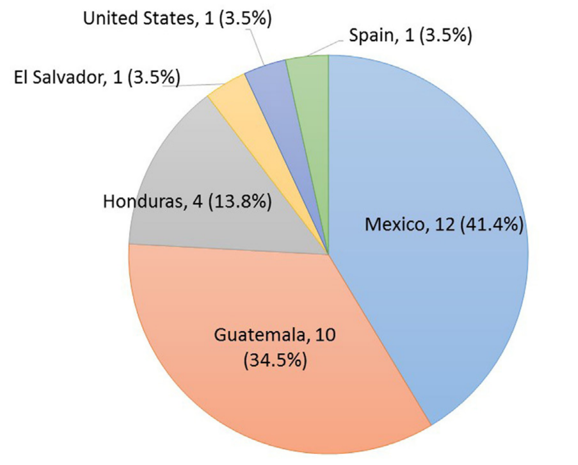

FIGURE 3 | **Distribution of country of origin for the U.S. dairy subjects**.

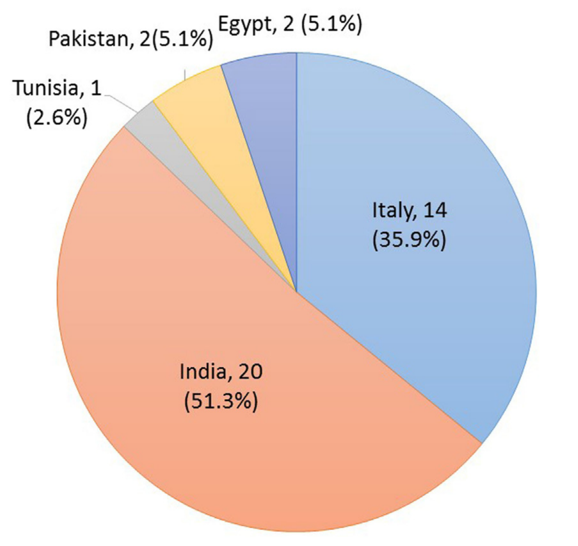

FIGURE 4 | **Distribution of country of origin for the Italian dairy subjects**.

anthropometric data indicated that the two subject populations were similar in stature but had significant differences in forward functional reach (**Table 1**). The mean age and work experience of workers employed in the Italian dairies was significantly greater than that of workers in U.S. dairies (**Table 1**). All, except one (U.S. woman), participants were males. The majority of workers were right-hand dominant; U.S. 97% and Italy 95%.

Muscle Activity Profiles

Profiles of muscle activity characterizing the normalized mean RMS, APDF at the 10th, 50th, and 90th percentiles and %MR were created for the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors for both U.S. and Italian dairy workers. As can be seen in **Tables 2** and **3**, upper limb muscle activity generally was greater among workers in the large-herd U.S. dairies than workers in small-herd Italian dairies. The ANOVA for mean RMS muscle activity indicated a significant interaction ($p < 0.001$) between the dairy size and upper limb muscle when examining the fixed effects. The simple main effects of the interactions (**Table 4**) revealed significantly greater mean RMS muscle activity for the biceps brachii ($p < 0.001$), upper trapezius ($p = 0.002$), and the wrist flexors ($p < 0.001$) for large-herd U.S. workers than small-herd Italian workers. However, the anterior deltoid ($p = 0.43$) and the wrist extensor ($p = 0.50$) muscles were not significantly different between the two worker groups.

The upper limb muscle activity expressed at the 50th and 90th percentile of the APDF was also assessed statistically. The ANOVA for the 50th percentile APDF indicated a significant interaction ($p < 0.001$). The simple main effects of these interactions (**Figure 5**) revealed significant greater activity for the biceps brachii ($p < 0.001$), upper trapezius ($p = 0.02$), and wrist flexors ($p = 0.0004$), but not for the anterior deltoid ($p = 0.97$) and the wrist extensors ($p = 0.84$) when comparing the two worker groups. The results of the 50th percentile APDF analysis were as expected because of the greater intensity and the higher volume of work tasks observed in large-herd U.S. dairy operations versus small-herd Italian dairy milking parlors.

The ANOVA for the 90th percentile APDF also revealed a significant interaction ($p < 0.001$). For the 90th percentile APDF, the simple main effects of the interactions (**Figure 6**) revealed significantly greater muscle activity only for the biceps brachii ($p < 0.001$) and not the other upper limb muscles, when comparing large-herd U.S. workers to small-herd Italian workers.

The ANOVA for %MR indicated a significant interaction between dairy size and the upper limb muscles assessed ($p < 0.001$). The simple main effects of the interactions indicated that the %MR was significantly greater for the anterior deltoid, upper trapezius, finger flexors, and finger flexors, but not for the biceps brachii ($p = 0.06$) among large-herd U.S. dairy workers relative to small-herd Italian workers. The %MR for all muscles during the working tasks was nearly double for the large-herd U.S. dairy workers as compared with the Italian small-herd dairy workers (**Figure 7**).

TABLE 1 | Anthropometric data for U.S. large-herd and Italian small-herd dairy workers.

	U.S. dairy workers mean (SD)	Italian dairy workers mean (SD)	$p < 0.05$
Age (SD)	29.7 (9.80)	43.1 (11.00)	*
Work experience (SD)	3.4 (4.80)	13.4 (10.75)	*
BMI (SD)	26.4 (4.20)	27.34 (3.95)	–
Body mass (SD)	73.9 (16.2)	79.0 (11.19)	–
Functional stature (SD)	166.4 (9.30)	165.0 (35.41)	–
Functional overhead reach (SD)	204.0 (23.18)	204.8 (31.05)	–
Functional forward reach (SD)	61.3 (3.50)	65.5 (4.90)	*
Shoulder height (SD)	140.1 (7.50)	145.1 (5.53)	–
Grip breadth (SD)	15.5 (2.33)	16.1 (1.22)	–

**Statistically significant difference between groups. Mean and (SD) are shown for each characteristic, N = 26 for large-herd U.S. workers, N = 39 for small-herd Italian workers. Age and work experience in years; body mass in kilograms; functional stature, forward functional overhead reach, functional forward reach, eye level height, shoulder height, waist height, and grip breadth in centimeters.*

TABLE 4 | Simple main effects of dairy size × muscle interaction from mean RMS muscle activity.

Muscle	Large-herd U.S. estimated RMS (%fMVC)	Small-herd Italian estimated RMS (%fMVC)	Estimated delta	Adjusted *p*-value
Anterior deltoid	9.62	8.25	1.37	0.42
Upper trapezius	13.47	8.03	5.44	0.002
Biceps brachii	19.32	6.85	12.47	<0.001
Wrist flexors	12.62	5.63	6.99	<0.001
Wrist extensors	13.90	15.06	–1.16	0.50

RMS, root mean square; %fMVC, percent functional maximum voluntary contraction.

TABLE 2 | Muscle activity profiles by muscle for large-herd U.S. dairies.

EMG variable	Upper trapezius mean (SD)	Anterior deltoid mean (SD)	Biceps brachii mean (SD)	Wrist flexors mean (SD)	Wrist extensors mean (SD)
10th percentile APDF	1.13 (2.07)	0.15 (0.39)	1.21 (2.22)	0.54 (0.92)	0.40 (0.59)
50th percentile APDF	9.28 (6.61)	3.49 (3.71)	14.58 (11.5)	7.41 (5.10)	9.75 (5.70)
90th percentile APDF	31.44 (21.04)	43.36 (36.26)	51.22 (38.86)	44.11 (31.13)	36.74 (21.40)
Mean RMS (%fMVC)	0.58 (9.19)	9.74 (3.71)	19.44 (13.87)	12.73 (6.24)	14.02 (7.73)
%MR	6.64 (7.24)	22.77 (12.75)	9.45 (7.34)	13.58 (8.25)	13.16 (6.69)

RMS, root mean square; APDF, amplitude probability distribution function; %fMVC, percent functional maximum voluntary contraction; %MR, percent muscular rest.

TABLE 3 | Muscle activity profiles by muscle for small-herd Italian dairies.

EMG variable	Upper trapezius mean (SD)	Anterior deltoid mean (SD)	Biceps brachii mean (SD)	Wrist flexors mean (SD)	Wrist extensors mean (SD)
10th percentile ADPF	0.66 (1.18)	0.16 (0.88)	0.076 (0.69)	0.15 (1.52)	0.23 (1.85)
50th percentile APDF	6.28 (4.29)	3.60 (3.99)	4.38 (2.73)	2.51 (2.67)	9.23 (5.58)
90th percentile APDF	19.50 (12.27)	29.61 (24.31)	19.75 (9.94)	35.85 (48.81)	43.43 (36.76)
Mean RMS (%fMVC)	8.46 (5.35)	8.26 (5.23)	6.86 (4.02)	5.64 (4.12)	14.60 (7.78)
%MR	0.59 (1.22)	4.98 (5.88)	5.36 (10.10)	4.67 (4.55)	5.67 (3.36)

RMS, root mean square; APDF, amplitude probability distribution function; %fMVC, percent functional maximum voluntary contraction; %MR, percent muscular rest.

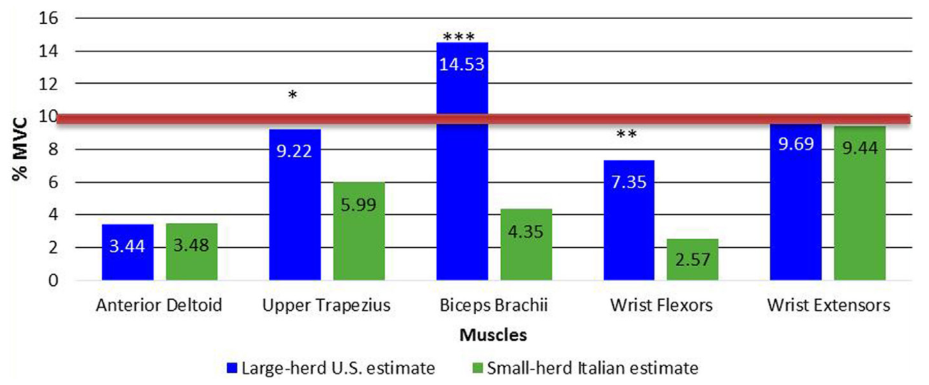

FIGURE 5 | Simple main effects of dairy size × muscle interaction for 50th percentile APDF. Red line indicates limit values that muscle load should not exceed (31). *$p = 0.02$, **$p = 0.004$, and ***$p < 0.001$. APDF, amplitude probability distribution function.

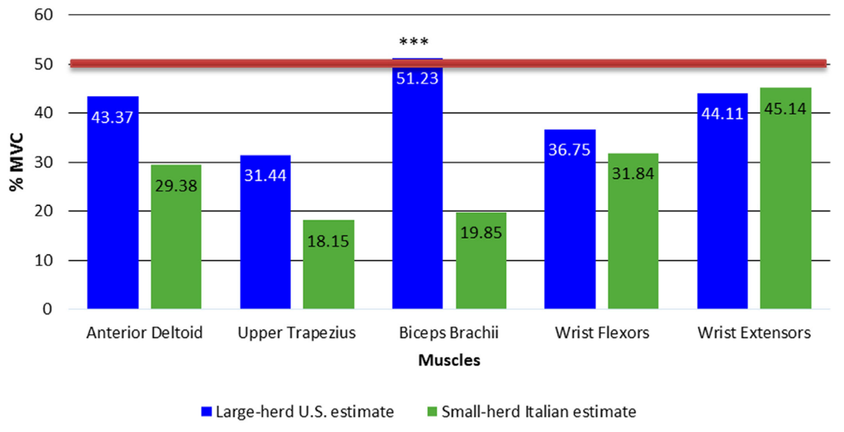

FIGURE 6 | Simple main effects of dairy size × muscle interaction for 90th percentile APDF. Red line indicates limit values that muscle load should not exceed (31). ***$p < 0.001$. APDF, amplitude probability distribution function.

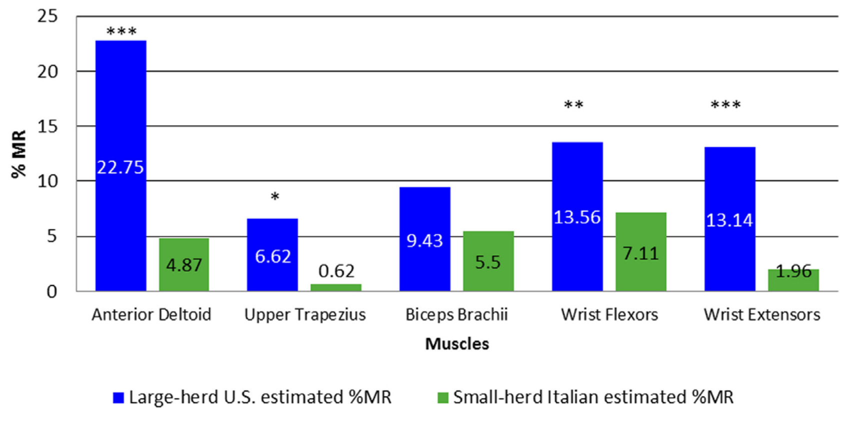

FIGURE 7 | Simple main effects of dairy size × muscle interaction for %MR. *$p = 0.004$, **$p = 0.002$, and ***$p < 0.001$. %MR, percent muscular rest as percentage of total sEMG recording time.

These results were not expected as large-herd dairies typically have a higher volume of milking work and a faster work pace compared with small-herd dairies, and therefore, less resting time for workers.

DISCUSSION

The primary objective of this investigation was to determine if there were differences in upper limb muscle activity during milking tasks performed by workers in large-herd U.S. dairy operations and workers in small-herd Italian dairies. This objective was accomplished through an analysis of the upper limb muscle activity profiles consisting of the mean RMS, APDF percentiles, and %MR for the upper trapezius, anterior deltoid, biceps brachii, wrist flexors, and wrist extensors for workers in both countries. Based on the previous studies (31) of muscular load, upper limits values have been proposed for preventing excessive muscular load that may contribute to fatigue and injury. The upper limit values for task durations of 1 h or more include: static load levels should not exceed 2% of MVC and must not exceed 5% of MVC; the 50th percentile load level should not exceed 10% of MVC and must not exceed 14% of MVC; and the peak loads (90th percentile) should not exceed 50% of MVC and must not exceed 70% of MVC (31).

The analysis of mean RMS, APDF percentiles, and %MR indicated that the milking activities affected the upper limb muscles differently based on large-herd U.S. workers and small-herd Italian dairy workers. The mean RMS analysis and 50th percentile APDF revealed that among the large-herd dairy workers in Colorado, there was greater intensity of muscle activity for the biceps brachii, upper trapezius, and the wrist flexors. Interestingly, the %MR was significantly greater among workers in the large-herd compared with the small-herd dairy operations. Workers from the large-herd farms had %MR nearly double that of workers on small-herd farms. However, anterior deltoid activity for both mean RMS and 50th percentile APDF were similar between the U.S. and Italian groups. Furthermore, the analyses of %MR revealed that the Italian dairy subjects had less rest for the anterior deltoid muscle. The relative consistency in anthropometrics between the two groups suggests that differences in muscle activity variables may be more related to differences in work methods between the large-herd U.S. and small-herd Italian dairies.

The mean herd size for the Coloradan dairies studied was approximately 2,200 cows, and the mean herd size in Italian dairies studied was 350 cows. In addition, Italian dairies milked their cows twice per day whereas, in the Coloradan dairies, the cows were milked three times per day. The larger herd size and increased frequency of milking in the Colorado dairies results in more cows milked per hour, and thus a faster work pace among milkers was often observed in industrialized milking operations (34). The work pace in the large-herd Colorado dairy parlors was so rapid that the investigators were required to remove all electrodes and equipment from subjects as they were taking a brief rest break between pens of cows. The faster paced high-intensity work in large-herd dairies may partially explain the increased muscle activity recorded among the workers in large-herd U.S. operations in this study. Although muscle activity relative to work pace has not been examined previously within the dairy industry, it has been examined in repetitive assembly work (35). Increasing work pace has been associated with increases, as well decreases, in regard to muscular load during work tasks (35, 36). This suggests that differences in work pace may or may not be related to the differences in muscle activity recorded among large-herd U.S. and small-herd Italian dairy workers.

The most unexpected result of this study was the large amount of %MR recorded among the large-herd U.S. parlor workers, nearly twice as much muscular rest as the smaller-herd Italian dairy parlor workers. This finding was unexpected because of the work pace and workload differences observed between large and small-herd operations. One possible explanation for the significant differences found in %MR between large-herd U.S. and small-herd Italian dairy workers was related to the management of the milking procedures by the dairies studied. All workers tested in the Coloradan dairies performed all five of the milking tasks, pre-dipping, stripping, wiping, attaching, and post-dipping. Work practices at the Italian dairies involved in this study were not as consistent as the U.S. dairies. Ten out of the 21 Italian dairies studied (involving 13 workers) did not perform the pre-dipping or post-dipping tasks as part of their normal milking routine. The definition of %MR requires that muscle activity fall below 0.5% fMVC for at least 0.25 s to be categorized as "rest." If only three out of five milking tasks were being performed, the task and muscle activity variation in these subjects could be reduced resulting in less muscular rest relative to total task time. Additionally, Italian dairy workers often had brief breaks (up to several minutes) during milking tasks and were required to perform other dairy work activities. These activities included pushing cows into the parlor, hosing off the pit floor and other areas, retrieving supplies, and completing antibiotics injections. Performing a variety of low effort tasks at a slow to moderate pace as in the above activities throughout the data collection period would contribute to the relatively low mean RMS activity and low %MR. In contrast, large-herd U.S. dairy workers performed a set of five tasks that were more repetitive but had rigid tack times that included micro breaks (>0.25 s). It was likely that the repetitive but frequent micro breaks also accounted for some of the increased %MR among the U.S. workers.

An additional procedural difference between U.S. and Italian dairies consisted of the stripping and wiping tasks. In the majority (80%) of Italian dairies, workers performed the stripping and wiping tasks together with the same upper limb motion. This time saving modification of combining two tasks into one further increased the simplification of work allowing the worker to perform tasks at a slower but more continuous pace. It is unlikely that the faster and higher intensity upper limb work observed in large-herd U.S. dairy parlors allows workers to sustain upper limb efforts without adequate rest (micro) breaks built into the work process. Thus, maintaining a healthy dairy workforce free from MSDs may only be possible if workers involved in high intensity repetitive work of the upper limb have adequate %MR.

Other researchers have reported that dairy milking is difficult and physically strenuous work in both large-herd and small-herd operations (7, 9, 10, 37). Additionally, investigators have reported high association between both large-herd and small-herd operations and MSS, MSDs, and workability (6, 9–11, 38–41). This study has clearly demonstrated that there are significant differences in the sEMG of upper limb muscles of large-herd U.S. dairy workers relative to small-herd Italian dairy workers. The differences revealed in sEMG and %MR among workers from Colorado and the Lombardy region are likely due in part to differences in work processes adopted by fast-paced industrialized large-herd dairies compared with the slower, but sustained work of small-herd dairies. Other factors accounting for some of the differences revealed in sEMG and %MR between the groups of workers studied may be related to procedural differences (need for pre-dipping and post-dipping of teats) that may also affect cow health and milk quality.

Limitations

Many of the limitations in this research were related to the large resources required for international studies of this magnitude. The sampling duration was limited to approximately 1 h per subject. Although the milking tasks are relatively repetitive, this short sampling time may not be representative of the entire shift, especially in Italian dairies where there was greater task variability. Large-herd dairy operations in the U.S. operate 8- to 12-h shifts. Thus, physiologic and muscle fatigue that may be present with full shift work was not measured due to the limited resources. Future research should consider the impact of muscle fatigue by examining full shift data.

The application of sEMG in occupational field studies has limitations due to methodological challenges associated with sEMG recordings. Some of these challenges include variables that can affect the sEMG signal other than the actual muscle activity such as electrode configuration, electrode placement and orientation, procedures for determining a functional MVC, cross talk from other muscles, movement artifact, muscle movement under the surface of the electrode, and tissue impedance and signal processing (30).

CONCLUSION

This is the largest multinational study related to the assessment of upper limb muscle activity among dairy workers. This study demonstrated significant differences in the sEMG of upper limb muscles during milking tasks for large-herd U.S. dairy workers relative to small-herd Italian dairy workers. Generally, mean RMS activity of the upper trapezius, biceps brachii, and finger flexors was significantly greater among workers at large-herd U.S. dairies than for workers at small-herd Italian dairies. However, the %MR was significantly greater for the anterior deltoid, upper trapezius, finger flexors, and finger flexors, but not for the biceps brachii among large-herd U.S. dairy workers relative to small-herd Italian dairy workers. The sEMG differences between the two worker groups were likely related to differences in work processes adopted by fast-paced industrialized large-herd dairies compared with the slower, but sustained work processes was performed at small-herd dairies. Other factors accounting for differences revealed in sEMG and %MR between the groups of workers may be related to differences in milking task methods.

AUTHOR CONTRIBUTIONS

All authors (FM, AM, CB, LM, CC, and JR) have (1) contributed substantially to the conception or design of the work and/or the acquisition, analysis, or interpretation of the data for the work, (2) participated in drafting the work or revising it critically for important intellectual content, (3) approved the final version to be published, and (4) agreed 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. JR was the local principal investigator and led academic for this part of the grant award. He led the design of the study, providing expertise in sEMG and occupational biomechanics, and made a significant contribution to both the interpretation of data and the writing of the final paper. FM was the doctoral researcher who contributed to study design, led data collection in Italy, contributed to data analysis, and wrote first draft. AM was the doctoral researcher who was involved in the design of the study, led the collection of U.S. data, conducted the data analysis, contributed to interpretation of data, and wrote the first draft. CB was the student researcher contributing to the interpretation of data and co-editing various drafts of the final paper. LM contributed significantly to the conception of the study, developed the manuscript sections on U.S. and Italy dairy profiles, and edited the final manuscript. CC contributed significantly to study conception and design, reviewed manuscripts for the intellectual content and accuracy.

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Perceptions of Health and Safety among Immigrant Latino/a Dairy Workers in the U.S.

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The U.S. dairy industry is increasingly relying on an immigrant workforce to help meet growing demands. Due to scant research, little is known about the factors related to workplace safety among this occupational group. The purpose of this study was to identify dairy worker perceptions of the barriers to and facilitators for enhancing workplace safety. Focus groups (FG) were conducted with 44 immigrant Latino/a workers from 2 dairies in South Dakota and 1 dairy in Colorado to gain firsthand insights into their work experiences. Interviews were conducted in Spanish, audio recorded, transcribed, and translated into English. Results were analyzed through a two-step qualitative coding process. The Contributing Factors in Accident Causation model was used as a guiding framework. Promising points of intervention identified were related to the workers, the work itself, the physical environment, equipment issues, the social–psychological environment, and management/organizational factors. Suggestions for how to improve safety outcomes in the dairy industry are provided. It is likely that the dairy industry will continue to employ a growing number of immigrant workers. Therefore, these findings have significant implications that can be used to guide the development of culturally congruent policies and practices.

Keywords: dairy industry, immigrant workers, Latino/a, safety, focus groups

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INTRODUCTION

The U.S. dairy industry ranks second among major world producers, supplying 14.6% of the world's milk supply (1). Since the introduction of new milking technologies, the industry has shifted toward a high efficiency model with increasing herd sizes (2). With the trend toward larger herds has come a growing reliance on an immigrant, primarily Latino/a, workforce (3). The federal government defines Latino/a (used interchangeably with Hispanic or of "Spanish origin") as "a person of Cuban, Mexican, Puerto Rican, South or Central American, or other Spanish culture or origin regardless of race" (4). Estimates of immigrant Latino/a workers on U.S. dairies have been reported as high as 94% (5).

Latinos/as tend to share a common set of values that are distinct from those found in mainstream American culture, including higher levels of in-group collectivism and familism (importance of family), stronger adherence to traditional gender roles, and greater acceptance of hierarchical power structures (6). It is difficult to generalize these commonalities given the great diversity across the Latino/a population in terms of country of origin, parental ethnicity (or ethnicities), length of time in the U.S., and levels of acculturation and language fluency (6). Clearly, managing a culturally diverse, primarily immigrant workforce poses unique challenges to dairy industry leaders when it comes to improving health and safety (7).

The demands of the dairy industry on worker health are many. On a daily basis, dairy workers are faced with diverse challenges, including high workload and time pressures, equipment failures and technological difficulties, and hazardous working conditions (8). As a result, the dairy industry has long been recognized as a high-risk occupation (9–12), characterized by elevated rates of injury, illness, and turnover (13). In fact, it is one of the few industries that experienced an increase in non-fatal injuries between 2010 and 2011 (14). Some of the more common occupational hazards include risks associated with machinery operation and repair, large animal handling, respiratory exposures, ergonomic risks including repetitive motions and high muscle forces required in parlor milking, and fatigue due to long hours and physical demands (2, 15–17). Although dairy operations employing more than 10 workers are subjected to regulations by the U.S. Department of Labor's Occupational Safety and Health Administration (OSHA), and currently, there are Local Emphasis Programs (LEP) targeting the dairy industry in several states as a result of work-related risks and fatalities; at this time, there is no federally mandated occupational health and safety training in the dairy industry (18). Advocacy groups, such as the Worker Justice Center of New York[1] and the United Farm Workers of America,[2] have highlighted the occupational health and safety of dairy workers as key issues due to recent incidents on dairy farms in several states.

Data regarding the incidence and prevalence of occupational injuries and illnesses among immigrant Latino/a dairy workers are scarce due to limitations in reporting systems and immigrant workers' reluctance to report injuries or illnesses due to fear of negative employment consequences (18). However, various factors suggest immigrant Latino/a workers may be at increased risk of work-related injury and illness. Many immigrant dairy workers are young, inexperienced, have limited education, know little to no English, are likely unaware of the harms of working on a dairy, and may not have developed the skills needed for learning job tasks and safety procedures. Smith-Jackson et al. (19) surveyed agricultural workers and found that Latino/a workers had lower safety self-efficacy compared with their Anglo-American counterparts. Many Latino/a workers also share a general health belief that injury and illness is outside of individual control, influencing their acceptance of occupational safety policies and procedures as well as their receptivity to safety training programs (20).

Immigrant workers also face a number of psychosocial conditions that are different from domestic workers, such as working and living in a foreign country away from family and friends and social isolation due to cultural and linguistic barriers (8). These circumstances may make immigrant workers more prone to depression, anxiety, substance abuse, and even suicide (21, 22). Due to these psychosocial conditions and the aforementioned daily challenges faced by dairy workers, they are also subjected to high levels of work stress. In fact, farming has been listed as 1 of the 10 most stressful occupations worldwide (23). These psychosocial strains could influence productivity and performance in addition to safety outcomes.

The promotion of health and safety are high priorities for dairy industry leaders, yet there has been little research exploring immigrant worker perceptions regarding the determining factors of these outcomes (13). With the growing prevalence of Latino/a workers in the U.S. dairy industry, and the U.S. workforce more generally, more research is needed to help organizations develop culturally congruent policies, practices, and programs in accordance with the job-related attitudes, values, and behaviors of Latino/a workers. This study conducted focus groups (FG) to better understand dairy worker perceptions of the barriers to and opportunities for enhanced safety, with the goal of developing culturally appropriate job and safety training programs for this underserved and vulnerable working population.

This study adopted a systems approach by attempting to shed light on the environmental, organizational, individual, and relational factors that influence dairy worker safety and productivity outcomes. Specifically, the Contributing Factors in Accident Causation model (24, 25) was used to guide the data collection and analysis. The Contributing Factors in Accident Causation model is a comprehensive model acknowledging the influential role of management, workers and coworkers, and the social–psychological environment in addition to the classic human factors variables, including the physical environment (i.e., influences in the environment), equipment (i.e., tools or machinery in the work environment), and the nature of the work tasks (i.e., design of the work itself). Shaw and Sanders (25) define management as all procedures, practices, and policies implemented by all levels of management across the organization. The workers and coworkers refer to the individual level physical and psychological limitations that contribute to the occurrence of accidents. Finally, the social/psychological environment refers to the social climate within the organization.

The overall goal of this study was to identify ways to develop more culturally congruent human resource policies, procedures, and practices tailored to immigrant Latino/a dairy workers in order to enhance safety in the dairy industry. Culturally congruent approaches are focused on adapting to the characteristics and needs of the culture that they are aiming to influence (26). As stated by Schenker and Gunderson (3), "with immigrants representing the majority of dairy workers, understanding the causes of illness and injury need to take into account the different perceptions, understanding, and behaviors that may be associated with being an immigrant … efforts to prevent injury and illness, or to treat those outcomes when they do occur, need to be sensitive to the realities of the immigrant worker" (pp. 185–186).

[1] www.wjcny.org
[2] www.ufw.org

MATERIALS AND METHODS

Procedures

A convenience sample of three dairies, one in Colorado and two in South Dakota, with which the research team had previously exiting contacts were recruited. Upon agreeing to participate, dairy owners were asked to announce the opportunity and encourage workers to participate. Recruitment flyers were posted in both English and Spanish. Only Latino/a dairy workers were eligible for participation.

Using the process of focus groups data collection followed Krueger (27), 45–95 min (M = 63.57, SD = 19.45) focus groups were conducted before or after work shifts on-site in a private room. Participants were asked to describe their previous work experience as well as their current job on the dairy, including tasks, responsibilities, and productivity influences as well as job training received. They were also asked about the quality and nature of communication with their manager/s and coworkers [e.g., "*How would you describe your experience communicating with your manager(s)?*"], with a focus on the influence of language and culture. The remainder of the interviews focused on safety (e.g., "*What does working safely around the dairy mean to you?*"), including perceived importance, organizational policies and procedures, and safety training. Interviews were conducted using a structured interview guide, but with flexibility to allow for the emergence of other topics perceived as important to the workers. Demographic information was not formally collected in order to make participants feel more comfortable being honest and open in their comments; however, some information (e.g., country of origin, time in dairy industry) was collected during the group discussions. Confidentiality was assured, and written consent was obtained from all participants before starting the focus groups. It was explained and emphasized to participants that their identity and input would be protected, no names or information would be collected that could breach confidentiality and anonymity, and managers and owners would not have access to who had said what. They were also assured that transcriptions and tapes would be kept at the University office in a locked file cabinet and that any written summaries, reports, or publications would only contain aggregate data and would not include the names of their respective dairies.

A Spanish bilingual–bicultural medical anthropologist conducted participant observation in the dairies, which involved living, working, and spending time with the workers in order to better understand their point of view. Participant observation was used to identify key activities and possible questions for the focus groups and to gain understanding of the workers' realities in their work place as well as outside with their families and peers in the trailers where they lived. This led to establishing rapport and building trust with workers, which was key to having more open conversations during focus groups. The medical anthropologist lived in the farm trailers and participated in all shifts and work activities on the dairy farm. These tasks included herding, feeding, milking and palpating the cows, helping veterinarians in the artificial insemination process, delivering calves, following protocols for after deliveries, working in the pastures, repairing irrigation systems, transportation and storage of cattle feed, checking the milk tanks, cleaning and helping with maintenance, and spending time after work at trailer gatherings, parties, lunches, etc. The participants integrated their knowledge in their role as co-researchers instead of mere subjects of the study.

All focus groups were conducted in Spanish and recorded. Audio recordings were translated into English and transcribed by a bilingual research assistant. Participants were compensated with a $35. All materials and procedures were approved by the Colorado State University Institutional Review Board before the initiation of the study.

Data Analysis

Data analysis was conducted in two stages. First, two members of the research team independently completed open coding of each transcript and met to generate an initial list of themes. Discrepant opinions were discussed until consensus was achieved. For instance, if one member of the research team thought a participant was referring to an existing safety procedure and the other member of the research team thought the participant was making a suggestion for a new safety procedure, they would reread the text together and discuss until agreement was achieved. Each theme was operationally defined and, when necessary, assigned example quotes from the transcripts to demonstrate the nature of the category for all coders. This initial list of themes was then fitted to the Contributing Factors in Accident Causation model (24), a comprehensive model acknowledging the influential role of management, the individual workers/coworkers and the social–psychological environment in addition to the classic human factors variables, including the physical environment, equipment, and the nature of the work itself. A Latino/a member of the research team with extensive experience training Latino/a dairy workers in the U.S. read all transcripts and audited the process. Two other members of the research team (an epidemiologist and an ergonomist) also audited the analysis process. One member of the research team then applied the final themes to all transcripts. A second member of the research team reviewed 25% of the coding for each of the seven transcripts to ensure appropriate application of the codes, resulting in 96% agreement.

RESULTS

A total of 44 dairy workers were interviewed during 2 focus groups at 1 South Dakota dairy ($N = 6$, $N = 6$), 2 at another South Dakota dairy ($N = 7$, $N = 7$), and 3 at a Colorado dairy ($N = 5$, $N = 6$, $N = 7$). Four participants from the Colorado dairy were female, and the rest of the participants across all focus groups were male. Approximately half of the participants were from Mexico, and the rest were from Central America (primarily Guatemala), Peru, and Puerto Rico. Themes reflect common feelings across participants and are presented in line with the Contributing Factors in Accident Causation model categories as follows: worker/coworker, work itself, physical environment, equipment, social–psychological environment, and management/organizational factors. When quoting participants, words in [brackets] were changed to protect the anonymity of the workers.

Worker/Coworker

Results at the individual level of the workers/coworkers fell under three main themes – occupational history/dairy experience, job-related knowledge, and work ethic/motivation.

Occupational History/Dairy Experience

Participants came from diverse occupational backgrounds and had been working at their respective dairies for anywhere between 2 and 26 years (M = 3.76 years, SD = 5.43 years, $N = 43$). Fourteen workers reported having work experience at other dairies between 2 months and 7 years (M = 2.37, SD = 2.20), and a handful of workers had experience milking cows by hand in their home country. Participants had an array of previous work experiences. The most often mentioned previous jobs were in construction, the meat industry (e.g., poultry processing plant, cattle ranch), various factories (camera, auto, boat, agrochemical products, plastics, food products, hot air balloons), and restaurants. Other previous jobs included blacksmith, businessman, housekeeper, florist, mall security, and mining. Some workers perceived their job in the dairy industry as safer compared to other jobs, such as working in a slaughterhouse.

Participants were asked to describe their reasons for selecting their current job. Some said they chose their job out of necessity, and others mentioned desirable aspects of the job, such as stability (often comparing the year-round work in the dairy industry to temporary/seasonal work in other industries), good pay compared to other industries/dairies, benefits (e.g., housing, medical benefits), and a preference for working with cows/animals. Some workers reported finding the job through a relative or friend, whereas others said it was merely the first job they found upon arriving in the U.S.

Job-Related Knowledge

Due to varying tenure in the dairy industry, some participants had much more job-related knowledge than others. Nonetheless, participants demonstrated serious gaps in knowledge in the areas of animal health and especially animal behavior, as well as human–animal interactions. Participants generally understood the relationship between careful observation, feeding, cleanliness and appropriate treatment of animals, and greater animal health and milk production. Some participants discussed how animal stress levels can affect their productivity and increase the risk of injuries in both animals and humans. Some common diseases and pathogens were mentioned as well as the possibility that animal diseases can be transmitted to humans through direct contact. When it comes to animal behavior, and more specifically, how to effectively and safely move animals from and to their pens, participants had a general lack of knowledge and reported a number of misconceptions. For instance, some expressed a viewpoint that cows become more obedient over time as they come to know and respect the workers, and some misidentified aggressiveness as playfulness and curiosity as aggression.

Work Ethic/Motivation

Many participants reported having a strong work ethic, with some pointing to pay and recognition as the primary drivers motivating them to work hard. A number of participants mentioned worker motivation as a key to achieve maximum performance, for instance, one worker explained:

> Of course, being motivated is very important for any person. If we're motivated we have more happiness, more ways to perform our jobs better. (FG #6)

Suggestions on how to improve worker motivation included recognizing hard work and providing rewards and incentives. Some expressed a desire for increased oversight, so dairy management could stay more informed about who was or was not doing their job well as a way to foster healthy competition. Others suggested holding more meetings between managers and workers to allow more opportunities for workers to express their opinions for how safety and productivity could be improved. For example, one worker recalled having such meetings in the past in which the workers would be rewarded for not making mistakes:

> There was a time when those meetings were held when they [dairy managers] would even bring us pizza and all three shifts got together and shared their different opinions about how the parlor was being managed …. And they used to motivate the workers to keep working and to keep good milk quality. (FG #6)

Work Itself

Overall, the participants described their jobs as having a great deal of challenging manual labor, time pressures, and related stress. Some described their job tasks as routine and repetitious, whereas others indicated it was non-routine. A number of participants expressed a lack of clarity regarding their role and daily responsibilities. While describing their work, participants primarily focused on the workload, shift and work schedule issues, and the hazards encountered while working with animals.

Workload

Overall, participants perceived their jobs as comprising the workload of two to three workers and highlighted the crucial role of teamwork in getting everything done. Participants emphasized the negative impact of high workload and pressure to work fast on safety and productivity. For example, one worker exclaimed:

> Sometimes one fees a lot of pressure because you have to clean pens, add bedding, do everything in one day. One is so rushed, that we don't do our job well. We do it well, but not as well as we should, with perfection. We do it rushing. (FG #3)

Workers expressed a desire for a decreased workload and more adequate time to do their jobs well. It was suggested that this would be accomplished either through more clearly delegated responsibilities or hiring additional workers.

Shift and Work Schedule

Two dairies had two 12-h work shifts and the third dairy had three 8-h work shifts. At one dairy, workers reported that they were often required to alternate working day and night shifts and emphasized the difficulty in adjusting to different work and sleep schedules. Participants reported having between 1 and 2 days off per week; some expressed frustration that days off were often during the week and not on weekends.

The primary issue in relation to work shifts was the lack of consistent oversight across shifts. Workers expressed frustration that work quality varies across shifts, but managers were not present to observe who was at fault in these situations, so everyone was blamed. Many of the night shift workers reported difficulty getting their needs met (e.g., equipment repairs) due to lack of management presence.

Animal Handling Hazards

Participants spoke about the hazards associated with animal handling, often illustrating their points by describing experiences of accidents and near misses. The most common injury mentioned was being kicked, trampled, or crushed by a cow. Participants described some of the strategies utilized to avoid animal handling hazards (e.g., staying quiet around the cows). However, due to the unpredictable nature of the cows, animal handling accidents were often viewed as non-preventable. One worker described animal handling hazards as follows:

> We are working with animals and we have to be in constant physical contact with them because I cannot make a cow go in the chute by telling her to get in. She is not going to get in. I have to be physically there with her. And sometimes she gets scared, and have stepped on or kicked me. There is no way to prevent this. (FG #2)

Getting more assistance from other workers was suggested as a way to help meet some of the demands inherent in their work and overcome animal handling hazards.

Physical Environment

Participants reported numerous environmental hazards on the dairy, including those related to electricity, unsafe conditions (e.g., wet floors, insufficient light, loose stairs), and exposure to chemicals, dust, manure, contaminated water, and other harmful substances. Sometimes, hazards were mentioned in relation to injuries or illnesses that had occurred as a result (of which some caused missed work days), and sometimes they were mentioned out of concern that they could pose a risk to human and/or animal health and safety. Overall, participants felt environmental hazards were not addressed in a timely fashion. Instances in which hazards were not attended to until multiple workers had been injured were also reported.

The milking parlor was mentioned as an especially high-risk area of the dairy, both due to the aforementioned environmental hazards and animal handling hazards. Participants stressed the importance of addressing environmental hazards more quickly and providing job-specific training on environmental hazards. The use of security camera footage was suggested as a useful way to identify environmental hazards that need to be addressed.

Equipment

Participants brought up a number of equipment-related factors that influenced safety and productivity outcomes on the dairy. These factors fell under three broad categories: machinery hazards, resource management issues, and personal protective equipment (PPE).

Machinery Hazards

Various hazards related to operating milking equipment, tractors, and other heavy machinery were reported. Some of these hazards were related to the dangerous nature of the machinery, whereas others were due to insufficient upkeep and maintenance. Some expressed an opinion that dairy managers should be responsible for maintaining equipment. For instance:

> In the milk machines there are a lot of issues that can cause accidents … [it] is not so much the worker's fault, but that the owner should be responsible of knowing that the machines are in good shape. (FG #6)

In addition to emphasizing more frequent maintenance, participants suggested the importance of job-specific training regarding correct and safe usage of hazardous machinery.

Resource Management Issues

Participants mentioned the negative impact of inadequate equipment maintenance on milk quality and their ability to be productive. Instances in which operations had to stop and when insufficient maintenance on one piece of machinery led to breakdowns of other machinery were also cited. Many participants, especially those working in the night shift, complained that they were unable to get equipment repaired in a timely fashion, either because they lacked the necessary training to do so themselves and were unable to access maintenance personnel or because they knew how to fix the problem but were not given permission or the necessary tools to do so. In these situations, some workers attempted to repair broken equipment themselves (even if against the rules), whereas others were afraid to try. In general, participants reported a great deal of resourcefulness and innovation in dealing with these issues. For instance, one worker explained:

> [We] have tools, but they're not the right tools for the job, so we have to look for something, to be creative with new ideas on how to solve problems. (FG #4)

Participants also reported inaction on behalf of management related to broken equipment and feared blame and angry reactions by managers when reporting broken machinery. For example, one worker described a situation in which he reported broken equipment to his manager as follows:

> I was told they would fix it right away, and nothing happened. Then the next day I would remind them to fix it and they would say as an excuse that they had forgotten

> about the [equipment], and that it would get fixed right away, again, I waited that day and until the next afternoon. I waited for an entire week for them to fix the [equipment] and I had to work and clean the parlor, and I ended up all wet. Wet my hands and sleeves. And if I keep getting wet, I mess up my hands then I'm not able to come to work. (FG #4)

Suggestions for how to overcome resource management issues included more frequent maintenance, providing the workers with permission and the necessary tools to fix the equipment themselves, and always having a maintenance person available.

Personal Protective Equipment

Participants commented on the availability and use of PPE, such as safety goggles, protective sleeves, gloves, and seat belts. Availability of PPE was varied. Two of the three dairies provided eye goggles and required workers to wear them in certain areas of the dairy or they would risk getting a warning. A number of reasons why workers resisted using PPE were mentioned, including not fully understanding risks, the negative impacts of PPE on their ability to perform their job (e.g., eye goggles fogging up), inconvenience (e.g., seat belts annoying to buckle and unbuckle), and obstinate attitudes. For example, one participant spoke to the discomfort some workers have with PPE due to lack of familiarity:

> Sometimes you feel uncomfortable using things that you never used before. For example for us [workers] it's very odd to work with gloves … at least in our home countries. Here [USA] for a number of things, we use different [safety gear]. (FG #7)

Participants generally recognized the importance of wearing PPE and expressed a desire to have more PPE available to them, specifically citing ear protection for those working in high noise areas, face masks to protect from small particle inhalation, and helmets to protect from cow kicks. Participants emphasized that PPE use should be mandatory in high-risk areas and enforced by dairy management.

Social–Psychological Environment

With regards to the social–psychological environment of the dairy, participants described their relationships with their fellow coworkers and dairy management, communication barriers and facilitators, and cultural differences that influenced their work relations.

Relationships with Coworkers and Dairy Management

Overall, participants described their relationships with their coworkers as positive and supportive, although some described tensions perceived as stemming from poor work performance and irresponsible behavior of others. Participants reported varying quality of relationships with their managers, ranging from mostly positive to mostly negative to non-existent. Workers with positive relationships with their managers emphasized the importance of trust and respect, for instance:

> Our supervisors have earned our trust, and here we treat each other like family. As of today, we have never been disrespectful to each other, and that is the most important thing. (FG #2)

Reports of negative interactions with managers, characterized by inaction, dismissiveness, blame, threats, and lack of respect, were common. Overall, participants felt undervalued and some attributed this to discrimination. For instance, one worker stated:

> They (bosses/managers) are seeing all the work that we are performing, they have seen good production an all that, good improvements and they don't value us. It's the devaluation of the person. The plain fact that we're Mexican does not mean that we're something strange. We're not less than another person. (FG #4)

Workers also commented on the lasting effects of negative treatment by managers:

> My supervisor could make threats to me, such as telling me that they're going to take my [house] away. One carries all those little things here [in my mind] for the rest of your life. (FG #2)

Communication

Participants spoke to the important role of communication in terms of promoting both safety and productivity. There were varying perceptions regarding the current state of communication on the dairy; some perceived it as sufficient and others identified room for improvement. The workers generally described within workgroup communication as strong but called for more integrated communication across areas of the dairy. For instance, one worker described communication on the dairy as follows:

> Most of the time, no one communicates, no one talks to each other. Each one does their own jobs, and communicate in our tasks, with coworkers in our own areas. But for example, I don't go tell them 'what do you think about how I am doing my job?' I don't speak with the milkers. (FG #1)

Many participants viewed language as a barrier to communication, describing the English/Spanish divide between workers and managers and the Spanish/Spanish divide among workers from different linguistic backgrounds. For instance, one worker explained the Spanish/Spanish divide as follows:

> The problem is sometimes English is not so much the problem, but instead is the diversity of Spanish because

> they're from all different parts and use different slangs and vocabulary. There are words I say that mean something different for them. The Spanish language is more complex than the English language (FG #3)

Unsurprisingly, efforts made by dairy management to learn some Spanish and by workers to learn some English were perceived as beneficial to facilitate communication. Participants mentioned the key role of English speaking coworkers as translators in facilitating communication with their bosses. However, participants also noted situations in which translators had misrepresented their words, often to their own benefit, which led to mistrust and frustration. For instance, one worker described having this experience as follows:

> If the manager [who speaks Spanish or the interpreter] is angry at you or does not like you, he can do you harm. Sometimes they don't say what it is (what you tell them) or sometimes they take the credit. What you say to them, a good idea about work, they keep it to themselves and then tell the boss. They keep it and then they don't speak on your behalf. They tell it so that it favors them. (FG #4)

Others disagreed with the assertion that language was a barrier and perceived other factors to be at the root of failed communication, such as personal issues between workers, managers not listening or paying attention to workers, or managers holding attitudes that they are above the workers. Suggestions to improve communication across the dairy included more frequent meetings, incentivizing cross-area teamwork, utilizing unbiased translators, providing English classes for workers, and creating an environment in which workers both have the opportunity to and feel comfortable speaking up about their needs.

Cultural Differences

Participants mentioned a number of perceived cultural differences between American and Latino/a culture and between different groups of Latinos/as. When asked about cultural differences, workers spoke to perceived racism and discrimination both within and outside of the dairy. Workers across all dairies felt that they were mistreated because of their ethnicity, and illustrated this by providing examples of how American workers are given preferential treatment (e.g., given higher pay and easier jobs, allowed to take more breaks), while Latino/a workers are treated as though they can be easily replaced. One worker described this dynamic as follows:

> When there's an accident that we [Latino/a workers] do, they [managers] take [the opportunity] to say 'Do you want a salary? With those things that you do, with all that you break?' But if they were American, they [managers] would say, 'We will immediately fix. It is under warranty.' They take it to the mechanic. Between them [American workers and managers], there's a union. Nothing happens. But if it is us … (FG #4)

Overall, participants highlighted important points of intervention to strengthen relations and communication between coworkers and dairy management and to overcome some of challenges stemming from cultural differences.

Management/Organizational Factors

The primary themes that fell under the category of management/organizational factors were job characteristics, safety policies and procedures, management characteristics, and training (both job and safety).

Job Characteristics

When describing the characteristics of their jobs, participants primarily focused on job titles and priorities, work organization, and benefits.

Job Titles and Priorities

Participants represented various job titles, including milker, calf caretaker, inseminator, hoof trimmer, corral keeper, and cow pushers (*pushadores*). Some described themselves as wildcards who were trained in all jobs and could fill in for absent workers. Overall, participants suggested a high level of lateral mobility across positions, primarily driven by high turnover and need rather than worker preferences or choice, and low levels of upward job mobility. Some believed upward job mobility was limited due to ethnicity, for example, one worker commented:

> Maybe there are people [immigrant workers] capable of becoming bosses, but the "patron" (the boss) will not accept a person that is not from here [U.S.]. (FG #6)

There was variation in tasks and responsibilities reported by workers holding the same job titles across the three dairies, suggesting the importance of training new workers even if they had previously held the same title at another dairy. When asked about their job priorities, participants emphasized the importance of cow health (e.g., making sure cows/calves are eating, detecting and treating sick cows, keeping corrals clean so cows do not get infected, understanding and treating cows well). Participants also mentioned the importance of personal safety and recognized the link between safety, performance, and success of the company. For example, one worker explained:

> Safety in a business, regardless of the size is very important, number one. Because safety goes hand in hand with production. If a company has low number of accidents, then it would receive more investments than a company that has too many and high amount of accidents. (FG #2)

When asked about job priorities, participants also stressed the importance of paying attention and being alert, following the rules, acting responsibly, and having good communication.

Work Organization

On the whole, participants felt that there was room for improvement in terms of the organization of their work. Although high levels of teamwork were reported within work groups, the overall organization of the dairies was described as siloed. Some suggested the importance of more integrated collaboration and frequent communication across different areas of the dairy to improve efficiency. For instance, one worker described:

> We're working in the same company, however, the workers at the milking parlor do their job, the calf feeders do their job, the outside people do their job. For example, I have had the opportunity to work in the milking parlor, and there are times that when they're behind, like we get behind. There's a lot of people there, but they don't lend a hand, don't help. It is like that. I've seen that it is the same in the other area …. I think it is lack of organization. (FG #1)

One dairy held monthly meetings to discuss safety and productivity, which facilitated cross-area communication and understanding; yet, the workers at this dairy still felt there was room for improvement. Suggestions for improving work organization included maximizing the fit and integration of jobs across the dairy and hiring more employees, so the same worker does not have to do multiple jobs at once.

Benefits

All dairies offered room and board to their workers; a number of additional benefits were provided across the dairies (e.g., English classes, vacation time, dental plans). Participants expressed frustration with low pay, lack of overtime pay, and inability to get a raise. For instance, one worker exclaimed:

> It's not good when the boss observes that you're a good worker and the years go by and there's no salary increase and it's always for the same amount of money. (FG #5)

Some Mexican participants reported an inability to advocate for pay raises after the dairy started employing Central American workers. For instance, once worker explained:

> If you go to the boss and ask for a salary increase, he would replace you for one of these [South American] workers. (FG #5)

Participants reported a lack of knowledge about health insurance; some were unaware of their coverage status, while others reported insufficient knowledge regarding the specifics of their coverage. Workers reported instances in which they had been led to believe that injuries and illnesses that occurred as a result of work would be covered, only later to find out that they would be financially responsible for all health-care costs.

Safety Policies and Procedures

Overall, participants reported limited knowledge regarding the safety policies and procedures of their dairy. It was unclear if this was due to a lack of policies or procedures or lack of awareness on behalf of the workers. Some participants stated that they were required to report incidents, but others were unsure of what to do in the event of an accident. On one of the dairies, the workers were required to talk to the owner before seeking treatment for illnesses or injuries, posing a particular problem for the night shift workers (i.e., because the owner was not available). One worker felt the managers did not believe workers when they reported accidents:

> The same applies for when you have an accident, that the supervisors don't believe you. When we have an accident, you go to the doctor, and they [managers] believe once they see the medical report of the accident. (FG #3)

When discussing safety policies and procedures, participants from one dairy suggested instituting regular doctor's exams and vaccinations (e.g., tetanus, flu, rabies) for all workers.

Management Characteristics

In addition to the dairy owners, the three dairies had a middle layer of managers/supervisors who dealt directly with the workers regarding day-to-day operations. Many workers held negative opinions of dairy management related to a lack of sufficient training, prioritizing cost cutting over worker well-being, taking credit for worker accomplishments, not seeing things from the workers' point of view, and failing to follow through. Participants perceived dairy management as prioritizing cow health over worker health, mentioning lack of first aid supplies as a way to highlight this point. For instance, when talking about an instance when a worker was kicked in the face by a cow, one worker described the managers' reactions as follows:

> Instead of seeing or worrying about a worker's face, they're looking at the cow's legs to make sure they are not hurt. (FG #4)

Many participants reported a lack of job control and limited ability to contradict their supervisors, even if they felt they were in the right. For instance, one worker described this as follows:

> You can't contradict the bosses. For them, what they do is always the best, even though we can tell them we know a better and more efficient way of doing the same thing. It's always what they say at the end. (FG #4)

Accessibility of managers was perceived as important to the workers' ability to successfully do their jobs, particularly in the event that something breaks down. Overall, managers were reported as being less accessible during night shifts.

Participants expressed a number of desired management characteristics, such as being available for communication, understanding of workers and company politics, fair and respectful when reprehending employees (rather than placing blame and getting angry), and well trained (in terms of the work itself and management). For example, one worker described the importance of having a well-trained manager as follows:

> It's very good when you have a supervisor, to have a supervisor that knows, that understands the job. Not

> to have a supervisor that comes to give orders and tell everybody how to do their jobs, without him really knowing how to do the job. (FG #1)

Other desired characteristics included continuously teaching and training workers, recognizing and appreciating hard work, working side by side with workers, maintaining a relationship based on trust and mutual learning with workers, following through on worker requests in a timely fashion, clearly delegating tasks and responsibilities, holding regular meetings with workers, listening to workers and giving them opportunities to demonstrate new ways of doing things, and providing enough oversight to ensure accountability and quality without micromanaging.

Training

Participants discussed the accessibility, content, frequency, and quality of training, both in terms of job/task training and safety training.

Job/Task Training

When asked about job and task training, the most commonly mentioned format consisted of on-the-job training provided by a coworker or superior; outside instructors and videos were also mentioned. Overall, participants perceived on-the-job training from an experienced coworker or manager as more valuable than training through a course or video. For instance, one worker commented on his preference for on-the-job training as follows:

> It's better to have a person [with experience] to teach step by step everything, with gestures, with his voice …. If you're watching a training video, and you get distracted for a while, then you missed a step you were supposed to do. You learn better if someone is there to teach you along the way. (FG #6)

The extent of training received varies across workers – some felt that they had received sufficient training, while some reported receiving no training at all. One worker explained situational factors that contributed to whether or not a new worker received job training:

> If the dairy is full, then they have the three milkers, and the boss (owner) is present, you'll kindly get trained. However, if you get started when someone is missing, they'll briefly tell you 'You need to do things this and that way' and you'll have to get started at that moment, and you're told to do it alone. (FG #6)

With regards to training content, workers noted a difference between training content and reality of the day-to-day job. The importance of making sure the individuals doing the training are experienced, educated, good at teaching, friendly, and considerate of the worker was emphasized. Overall, workers expressed a desire to receive additional training, especially focusing on tips to improve task effectiveness and efficiency and explanations for why certain things should be done in certain ways.

Safety Training

Overall, participants perceived safety training as important and valuable. Some reported receiving monthly safety trainings, whereas others reported receiving no safety training at all. For instance, one participant explained:

> Here [at this dairy] I have only had 3 jobs. And here I have never been told what risks are involved with the job, or what type of accidents I could suffer. Nothing. (FG #6)

Although some participants stressed the importance of safety training for newer, less experienced workers, others felt that it was necessary for safety training to be ongoing as a way to remind even the more experienced workers of how to stay safe on the job. For instance, when asked about safety training, one worker explained:

> They're important and it is good because this way one can also be reminded about the accidents that happen, and avoid committing the same mistake that one sees in the videos, what someone did wrong and how it got hurt. (FG #7)

Various safety training formats were mentioned, including safety meetings, formal courses, videos and written materials, and informal training from coworkers. Participants also mentioned learning about safety through accidents and near misses and through previous jobs. In-person and video-based safety trainings were generally perceived as more beneficial compared to written formats. For example, when asked about video versus written training materials, one worker commented:

> [Video format] is better because with the video you get to watch and not read it. Maybe you read it and you don't understand it. By watching, you get a clearer idea. (FG #3)

Some participants complained that the safety training received was not specific to dairy work, but rather focused on general safety issues (e.g., electrical safety, CPR, weather issues, first aid) or other issues not related to dairy work. For instance, one worker exclaimed:

> The safety training videos teach us how to lift boxes, but here at the dairy we don't lift heavy boxes. It's rare the time we have to do such a thing. (FG #2)

Some participants suggested that safety training is necessary but not sufficient to protect worker health, stressing the importance of workers taking responsibility for their own and others' safety as well as the role of machinery maintenance and upkeep.

DISCUSSION

The findings from this study provide important insights into the experiences of immigrant Latino/a dairy workers, with a focus on the factors that influence health and safety outcomes. The participants identified numerous individual, organizational, environmental, and social–psychological points of intervention for better managing, training, and creating a more safe and productive environment for immigrant dairy workers. Many of the factors identified (e.g., job control, psychological demands) fall under the National Occupational Research Agenda's organization of work framework, which refers to a range of organizational practices related to production, management, and the ways in which jobs are designed and performed (28). There is substantial research linking organization of work components with various worker health and safety outcomes [e.g., Ref. (29–32)].

Overall, participants advocated for enhanced cross-area integration and a greater voice given to workers. Workload and shift/scheduling issues were identified as particularly stress-inducing job characteristics; efforts should be made to reduce these stressors. Participants emphasized the need to more quickly address environmental hazards and equipment issues during all shifts in order to prevent risks to animal and human health and to optimize productivity. By promptly addressing workers' concerns and having protocols for communicating when problems arise, managers could reduce issues with productivity and alleviate workers' frustration.

Of concern, participants demonstrated serious gaps in knowledge in the areas of animal health, animal behavior, and human–animal interactions. Participants also reported limited awareness of transmission of zoonotic diseases. Farm animals are an important source of diseases to humans through direct contact with animals, their environment, or ingestion of contaminated food (33, 34), and agricultural workers in frequent contact with animals are at high risk of zoonotic diseases (35). Culturally sensitive training interventions that focus on increasing awareness and modifying behaviors to reduce exposure to zoonotic risks are essential. One of such programs is currently being evaluated for effectiveness by the authors.

Many participants shared a common belief that animal health and safety was prioritized over worker health and safety, a perception found among other immigrant dairy workers in the U.S. (18). It is essential that dairy management develop and communicate comprehensive safety policies and procedures to create a strong safety culture and make workers feel as though their safety is considered as important and critical to the success of the dairy (as much, if not more so, than animal safety). Many participants requested additional PPE that should be made available and required for use, particularly in high-risk areas of the dairy. Additional PPE should be introduced with training regarding its importance and proper use.

In terms of the social–psychological environment, participants identified a number of strategies to overcome communication barriers, including the use of unbiased interpreters, holding more frequent meetings, and creating an environment that promotes frequent and transparent communication across all levels and areas of the dairy. Cultural stereotypes and perceived discrimination surfaced as prominent aspects of the social–psychological environment, suggesting the importance of clearing up negative misperceptions and making a concerted effort to reduce unfair treatment based on ethnicity. These issues are especially important to address given that perceptions of discrimination have been linked positively with work tension (36, 37) and intentions to quit (38, 39), and negatively with job satisfaction (36, 37, 40) and organizational commitment (36, 38). In addition, other cultural factors are important to consider such as the concept of family and its impact in setting priorities, the notion of respect of authority, the idea of teamwork, and the perceptions of health related to the work tasks. Social class, level of education, and immigration status are also relevant aspects to take into consideration.

These results have a number of important implications for dairy management. Participants' perspectives on the positive aspects of their jobs can be leveraged to recruit and retain skilled workers, a noted challenge within the dairy industry (41). Many participants indicated poor relations with dairy managers, characterized by low levels of manager accessibility, less than adequate communication, and high levels of management mistrust and inaction. Marín et al. (42) found similar supervisory practices toward Latino/a immigrant workers in poultry processing plants in North Carolina. It appears that at least some of the managers from the dairies involved in this study would benefit from participation in management and leadership training programs. Previous research has demonstrated a link between leadership and improved safety climate and reduced injury rates (43–45).

Participants called for enhanced clarity from management regarding benefits (especially health insurance) and role responsibilities. Many participants also identified ways in which they felt had been unfairly treated, particularly in terms of job mobility, benefits, and pay. Employee perceptions of fairness are associated with positive outcomes, such as performance, organizational commitment, and job satisfaction, whereas perceptions of injustice are linked with negative outcomes, such as high turnover and counterproductive work behaviors (46, 47). Dairy managers should also focus on enhancing perceived job control, in terms of both task autonomy and employee engagement in decision-making, as perceived control has been associated with high levels of performance and motivation, lower stress, and reduced absenteeism and turnover (48). Participants also expressed a strong desire to receive more recognition and appreciation for their work as a way to improve morale and foster motivation. It is important that workers feel valued and listened to.

The findings from this study also have a number of implications for job and safety training. A majority of participants had no previous dairy experience and many had no experience working with animals, suggesting the importance of ensuring all employees receive adequate job task and safety training. Given the scope of variability in previous work experience, it is important not to assume even basic task and safety knowledge among workers (18). Participants spoke to the need for providing initial training to new employees as well as refresher training to those with more experience, suggesting that training should be approached as an ongoing process rather than a one-time event. Training programs should also recognize and account for the diversity across workers in terms of language, education level, and culture (18). Utilizing various different media (e.g., flip charts, fotonovelas, theater) and formats (e.g., visual, verbal, hands on) can help to accommodate different backgrounds and learning preferences. Participants called for more in-person, on-the-job training delivered by experienced and qualified trainers. There is a large literature base suggesting that trainings based on active participation are more effective than lecture-based trainings (49). Additionally, training should focus on correcting misperceptions regarding the preventability of animal handling accidents. Training content should be carefully tailored to reflect the demands and day-to-day realities of dairy work. There have been recent efforts attempting to design culturally relevant, bilingual safety training based on the attitudes, beliefs and practices of Latino/a dairy workers (50); however, more research is needed to assess the effectiveness of these programs.

There are a number of limitations that affect the generalizability of these findings, including the small sample size and the use of convenience sampling methodology to recruit dairies. Workers from different dairies that would not know each other would have been optimal. This was considered and logistics to find a convenient place for everyone, including travel time, requests for time off, and lodging, were major obstacles. It is also likely that participants held back in their comments out of fear that full disclosure would lead to negative consequences stemming from dynamics between workers and dairy management and/or among coworkers (e.g., angry management, job loss). However, the focus groups were a vehicle to start a conversation initiated with the participant observation where rapport had been established and, as previously mentioned, a number of steps were taken to reduce the workers' fear of retribution.

Future research should attempt to capture the perspectives of a larger number of dairy workers from a representative sample of U.S. dairies based on geographic location and size. It is also important for future research to gain the perspectives of dairy management in terms of the best ways to enhance safety and productivity.

CONCLUSION

With the growing prevalence of immigrant Latinos/as in the U.S. workforce, evidence-based research is needed to help organizations develop culturally congruent policies and practices in accordance with the job-related attitudes, values, and behaviors of these workers (51). Results of this study shed light on dairy workers' perceptions regarding workplace health and safety risks. Although dairy operations are perceived as risky environments, the role of management was clearly highlighted as pivotal in setting a culture of safety and health. Management's leadership skills can influence workers' perceptions dramatically. Practicing timely and clear communication, promptly addressing health and safety concerns, readily supplying necessary tools and PPE, and providing adequate feedback can reduce the frustrations shared by participants and improve motivation among dairy workers. Dairy operations should invest not only in culturally congruent training programs for their workers but also in the development of middle and top managers' human resource management and leadership skills. Despite the inherent limitations, this study serves as a first step toward understanding immigrant Latino/a dairy worker perspectives related to health and safety.

AUTHOR CONTRIBUTIONS

All authors (LM, FP, TT, LS, JR, and NR-M) have (1) contributed substantially to the conception or design of the work and/or the acquisition, analysis, or interpretation of the data for the work, (2) participated in drafting the work or revising it critically for important intellectual content, (3) approved the final version to be published, and (4) agreed 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. LM contributed to the design of the work, analysis and interpretation of the data, and drafting and revising of the manuscript. FP and TT contributed to the design of the work, acquisition, analysis, and interpretation of the data, and the drafting and revising of the manuscript. LS and JR contributed to the design of the work and the drafting and revising of the manuscript. NR contributed to the analysis and interpretation of the data, and the drafting and revising of the manuscript.

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Awareness and Need for Knowledge of Health and Safety among Dairy Farmers Interviewed in Uganda

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Introduction: Safe working conditions are essential for healthy living and for ensuring food security among farmers and farm communities in developing countries. There is limited research on this topic, and documentation is essential to understand and change patterns of human health and safety.

Methods: In May 2014, six male and female farmers on four dairy farms in Uganda and a female veterinarian were interviewed about their awareness and attitudes to agricultural risk factors, health, and safety. In addition, transect walks were conducted on the four dairy farms.

Results: The dairy farmers reported health and safety concerns, e.g., diarrhea, coughs, fever, cuts while using machetes in plantations, bruises when handling animals, and dizziness and poisoning symptoms from using different agrochemicals, and considered these an occupational hazard. The most important topic mentioned was the use of agrochemicals and drugs on livestock. The farmers spray their animals with insecticides to prevent ticks, lice, tsetse flies, and other biting nuisance flies, using a backpack or hand sprayer. Spraying is conducted without personal protection equipment, which is considered too expensive and difficult to obtain. The farmers reported that they usually feel dizzy, vomit, and have pain and a burning feeling in their face and eyes after spraying. The symptoms are sometimes so severe that they require treatment. In such cases, the farmers buy medication without a prescription at the local drugstore, where the storekeeper often has limited or no knowledge of agrochemicals or drugs except for dosage. Agricultural health and safety training in the region is non-existent, and the farmers expressed a need and desire for improvements in this area.

Conclusion: The level of knowledge and awareness of agricultural health and safety risks, disease, and injury prevention among the Ugandan dairy farmers interviewed was low. The farmers mentioned few agriculture-related complaints, injuries, or diseases except poisoning from using agrochemicals. Training on health and safety in Ugandan agriculture is urgently needed.

Keywords: dairy farmers, physically demanding, risk factors, agrochemicals, injuries, developing countries, Uganda

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INTRODUCTION

Agriculture engages about 1.3 billion people worldwide, almost 60% of whom live in developing countries (1–5). The agriculture sector comprises different branches, such as crop, horticultural, and livestock production, which involve a range of work tasks resulting in agricultural workers being exposed to a diverse array of occupational hazards (2, 6). Agriculture has been identified as one of the most hazardous sectors in the world, and it is estimated that of 335,000 fatal work-related accidents occurring worldwide every year, some 170,000 involve agricultural workers (4). Large numbers of the world's agricultural workers also suffer serious work-related injuries and diseases caused by machinery, chemicals, and animals (4).

Although agricultural farms in many developed countries are highly mechanized, operate on a large scale and tend to practice monoculture, farming in many developing countries is much more labor-intensive, non-mechanized, and integrates both crop and livestock production. These differences have a significant bearing on the levels of risk awareness and attitudes to preventing injuries and diseases within the sector (3–5).

It is well known that dairy farming is associated with demanding and hazardous risk factors, such as difficult working postures and movements and repetitive and monotonous work tasks giving rise to musculoskeletal disorders. It is also associated with exposure to noise, vibration, dust, weather, pesticides, zoonotic diseases (diseases and infections that are naturally transmitted between vertebrate animals and humans), excessively long hours, and handling of livestock, which can affect the health and safety of farmers and farm workers (2, 5, 7–15). Additional factors identified as contributing to injuries and ill-health among the farm population are fatigue, time pressure, stress, poor equipment maintenance, lack of personal protection equipment (PPE), poor knowledge and awareness, and human error (16, 17).

Many of these hazards and health and safety issues related to dairy farming are more or less similar worldwide, but vary depending on production system, socioeconomic context, and conditions (6, 16, 18–20). Systematic studies on agriculture-related health and safety in developing countries are scarce (21). The few studies available specifically addressing occupational health and safety issues among farm populations in Africa show high incidences of self-reported acute and chronic injuries (22–24), comprehensive exposure to agrochemicals, a high incidence of poisoning (25–27), and a high incidence of infectious diseases relating to agriculture (28). Very few studies have examined the health and safety of farmers and their families in Uganda. Records from the 1980s reveal that the annual number of cases of pesticide poisoning in Uganda at that time was 272,000 (29). Kobusingye et al. (24) found that injuries among people living in rural areas gave rise to an annual mortality rate of 92 per 100,000 and that injury-related disabilities had a prevalence proportion of 0.7%.

The available research regarding the health and safety of farmers in developing countries is limited, and documentation is essential in order to understand and change behavioral patterns and attitudes in this regard.

The overall aim of this study was to increase knowledge and highlight agriculture-related human health and safety issues, which in future could lead to fewer injuries, illnesses, and other negative consequences for the livelihood of farmers and their families in developing countries. To achieve this aim, interviews were conducted with Ugandan dairy farmers and family members regarding their attitudes, how they perceived risk factors, health, and safety in an agricultural context, and how it affected their daily lives and livelihood at large. The study also focused on lifting existing needs, possibilities, and obstacles for future research regarding issues on agricultural health and safety among dairy farmers in Uganda.

MATERIALS AND METHODS

Study Design and Ethical Aspects

The study comprised a qualitative, small-scale, cross-sectional study using semi-structured interviews and transect walks. The intention was not to generalize, but to explore and highlight Ugandan dairy farmers' subjective knowledge and experiences, as well as needs, possibilities, and obstacles regarding agricultural health and safety and the effect on livelihood (30). For this purpose, inductive qualitative methodology was appropriate (31, 32). The motive for choosing a qualitative approach using interviews and transect walks was to create a more nuanced picture, gain a deeper understanding of the participants' perceptions and experiences, and obtain comparable and reliable data, while, at the same time, keeping a fairly open framework to follow-up leads (33). These methods were chosen instead of a questionnaire, as farmers are difficult to reach by postal mail and illiteracy among farmers is common in the region. The participants were provided with oral information about the project and the purpose of the study, and anonymity and the voluntary nature of their participation were explained. No application was made to the Ethical Committee as the study was a pilot study, but current national guidelines based on the Helsinki Declaration concerning research ethics, anonymity, voluntariness, confidentiality, and retention of data were considered and fulfilled (34). The study was conducted during the period of May 19–23, 2014 (30).

Study Participants

Agricultural statistics presented here on number of farming households (farms), farmers, animals, and herd sizes in Uganda are based on estimates provided by the Ministry of Agriculture, Animal Industry and Fisheries (35). According to the latest National Livestock Census (35, 36), the number of cattle and households owing cattle in 2008 was estimated to be 11.4 and 1.7 million, respectively. Households owing cattle represented 26% of all households in Uganda in 2008. More than 90% of Ugandan cattle farmers are smallholders with an average herd size of seven cattle per household and a milk production level of 8.5 l per cow and week (no information is available on dairy cow herd size) (35–37). The Western region has the highest density of dairy farmers and milked cows in the country (0.41 million milked cows, compared with 1.52 for the entire country) (36, 37). Therefore, study participants representative of an average Ugandan dairy farm were chosen from the cattle-intensive Western Uganda (specifically from Mbarara district, part of the

Ankole sub-region). Important criteria for participation were that the farmers had a dairy production enterprise representative for Uganda and were willing to share experiences and knowledge about agricultural risks and health and safety issues. The study participants were a convenience sample selected by the Ugandan University colleague, an extension advisor, the corresponding author, and in accordance with the abovementioned criteria. The study ended up comprising four dairy farms, three male and one female dairy farmer, a female farm family member, a hired male dairy farm worker, and a female veterinarian who was also a university lecturer. A description of the farms and participants is provided in the Section "Results" of this paper.

Interviews and Transect Walks

An interview guide was developed and tested by the research team (both authors) prior to the study and included questions about:

- Demographics of the dairy farms (e.g., size, ownership, subsistence farming or products for sale in the local market, workforce, type and number of cattle and other animals, animal health, handling of animal manure, type and size of crop production, provider and use of medication on animals and humans, and pesticides on crops)
- Participants (e.g., age, gender, education, marital status, and household size).
- Description of the daily work tasks.
- *Description of tools or equipment used on the farm.*
- *Perceived health status (e.g., describe what you think is good/poor health for you. How would you describe your own and your family's health? Do you experience some of the following symptoms: fever and chills, muscle and joint pain, chronic fatigue, headache, nausea, chest pain, diarrhea, vomiting, coughing or breathing problems, skin itching, and how often?)*
- *Occurrence of injuries (e.g., Have you or someone in your family been injured when farming? What happened? Kind of injury?* (fracture, wound, bite, kick, crushing, burn, toxic or corrosive substance, etc.), *Injured body part*? (face, eyes, neck, back, arms/legs, fingers, chest, stomach, internal/external injuries), *Did the injury require medical treatment? Do you still suffer from the injury?)*

The interview guide also contained questions about the participants' perception, attitude, and awareness of:

- Hazardous, physically and mentally demanding work tasks and situations (e.g., *Do you think there are risks related to your health and safety as a dairy farmer and how would you describe these risks?*)
- Hazardous farm chemicals and drugs (*Which type of farm chemicals and drugs do you use on the dairy farm? How and when do you use them? What do you do to protect yourself when you use chemicals and drugs?*).
- How to avoid getting sick or injured when farming.
- Possible benefits of a healthy and safe farm environment.
- Availability and demand for information and practical training in human health and safety when farming (e.g., *Have you received information or training regarding agricultural health and safety? Would you like information or training about this? In what form and what should the information or training contain? How could dairy farming be made more healthy and safe for you and your family in the future?)*

All interviews and transect walks were conducted on the dairy farms except for one interview, which was conducted at the university (the veterinarian). The individual interviews lasted for about 2 h, followed by 1–2 h of transect walks on the dairy farm. The transect walks took in the farm premises, the animal and machine sheds, and the pastures/crops. The interviews were held by the research team. Three of the interviews were performed in English and four interviews were translated into the local language of the Ankole tribe (Runyankole) and back-translated to English by the Ugandan colleague. To support the researchers' notes and with the agreement of the participants, the interviews and transect walks were documented by tape recording and photographing.

Data Analysis

Content analysis of the data collected was chosen as a qualitative validated phenomenological method (31, 32, 38). The collected material from the interviews and transect walks was anonymized and transcribed. After transcription, the text was carefully and repeatedly read to gain familiarity with the content, and all information related to the questions in the interview guide was marked, coded, and summarized at individual level. Reflections concerning the following issues were considered in the texts: What did the text contain? What did the participants say? What was important for the participants? How should the experiences and statements of the participants be interpreted? The individual texts were then analyzed and themes relating to the main issues raised by the participants were identified. These themes were summarized, and statements that described the participants' responses were formulated according to qualitative research procedures (31, 32, 38). Transcription, analysis, and compilation of results were carried out by both authors of this paper and are presented and discussed in the following sections.

RESULTS

Description of the Dairy Farms and Participants

The study comprised in total four dairy farms and interviews with six farmers and one veterinarian. Three of the four farms and farmers visited in the Mbarara District in Uganda were characterized by:

- Practising smallholder agro-pastoral farming (**Figure 1**) (considered here as subsistence farms with no produce surplus for market sale).
- Average herd size of 7–13 dairy cows and heifers of the traditional local Ankole breed or crossbreeds with Holstein Friesian and Ayrshire.
- 10 goats and chickens.
- Three to five pigs and sheep.
- Besides pasture for the animals, the farms grew plantain (cooking banana), sweet potatoes, beans, cassava, yams, millet, sorghum, and groundnuts on a few hectares.

FIGURE 1 | **Agro-pastoral farming in Western Uganda**. Copyright © Christina Lunner-Kolstrup.

- Hand tools, such as machetes, long sticks (to cut banana leaves), shovels, and hoes, were the only equipment used to cultivate the land.
- Owned and managed by male farmers.
- Little or no formal education.
- 40–70 years of age.
- Wives and children were active in farming.

The fourth farm was a large farm in a Ugandan perspective, consisting of three smaller farms, and was characterized by:

- Crop, timber, and dairy production and breeding as the respective production focus on the farms.
- 30 dairy cows and in total 125 cattle of Holstein Friesian, Jersey, and Ayrshire breed.
- 25 goats and sheep for meat and for protection of the dairy cows (potential predators choose smaller animals over larger).
- Milk yield of about 400 l of milk per day, some of which was used for household consumption, but the majority of which was sold in the market.
- 80 ha in size and included pasture, Napier grass (silage) for animal feed, timber production for building maintenance, plantain and the traditional vegetables abovementioned for human consumption.
- The land was cultivated using traditional hand tools.
- This dairy farm had a milking machine and a cooler (although they were not working because of lack of spare parts).
- A biogas unit for electricity production and a hydropower for water supply for both farming and household.
- Owned and managed by a female widow in her 60s and her 25 employees.
- Before retirement, this female farmer had worked for local government and was well educated.

Daily Work Tasks

In Uganda, females are usually responsible for household chores and children, working in the plantation and managing smaller livestock, such as pigs, sheep, goats, and poultry. Males are often responsible for the cattle, milking dairy cows, participating in plantation work if needed, and in some cases having off-farm jobs.

A usual working day on the dairy farms visited often started early in the morning at 6 a.m. with prayer, a bath, the males milking the dairy cows, and the females feeding and watering the animals. After breakfast, work was done in the plantation and vegetable garden and the wife and daughters prepared lunch (on the large dairy farm, a young female was employed as a cook and also took care of the poultry). After lunch and rest for a few hours, the afternoon was spent in the plantation, vegetable garden, on tailoring, maintenance, household chores and cooking, and milking, feeding, and watering the animals before dinner at 6 p.m. The day ended with socializing with family and neighbors, prayer, and sleeping at 9 p.m.

Hazardous and Demanding Work Tasks and Situation

Knowledge and awareness of health and safety risks associated with dairy farming and agriculture and prevention of injuries and diseases when farming were very low among all interviewees except for the female dairy farmer and the veterinarian. The dairy farmers, workers, and family members reported few complaints, injuries, or diseases related to dairy farming and agriculture in general. However, it was obvious from the dairy farmers' responses that health and safety concerns, e.g., diarrhea, cough, fever, cuts while using machetes in the plantation, bruises when handling the animals, and symptoms of poisoning from using insecticides on the animals, were normal conditions, not worth talking about and considered an occupational hazard in farming. The female dairy farmer and the veterinarian explained that Ugandan farmers consider life in itself to be hard (work) and that the mental pressure and concerns regarding drought, not getting enough food for the animals and the family, having to pay for expensive medication in the event of illness and school fees for the children are more significant than a few cuts, bruises, and diseases.

However, during the interviews and transect walks, the participants highlighted several issues: hand milking the dairy cows involved squatting and kneeling, carrying the backpack sprayer with insecticide for spraying the animals, and working in the plantation were considered physically demanding and sometimes hazardous work tasks (**Figure 2**).

> "Milking the cows is hard and my back hurts. I know I can't milk anymore when I get old; but then I will have my children and grandchildren doing the work (Dairy farmer)"

Dairy farmers often opt to tie the hind legs of dairy cows with a rope during milking, as a safety precaution to prevent them kicking the milker (**Figure 2**).

> "The flies are a nuisance to us and the cows and when we milk they get irritated. Milking in a shed with the cow tied would be safer than milking in the field, but we can't afford it (Dairy farmer)"

FIGURE 2 | Hand milking involving squatting and kneeling. Copyright © Christina Lunner-Kolstrup.

FIGURE 3 | Farmers bringing their local long-horned Ankole cows to pasture. Copyright © Christina Lunner-Kolstrup.

Farmers in Western Uganda are traditional herdsmen, living closely with their animals for years, and have good knowledge about animal behavior. However, animals and animal handling were mentioned as possible risk factors, especially in situations when the animals are restrained, giving birth, or being moved (**Figure 3**). Deworming or other treatment that involved restraining animals was considered as a hazardous and physically demanding situation, as no restraining facilities were available, only human labor.

> "Few farmers put up crushes for just handling the animals. It is a risky task treating unknown and semi-domesticated animals. But farmers are not to blame; we have not taught and trained them (farmers). The farmers' don't have much labour, so they call upon neighbours or pay hired workers to help handling the animals (Veterinarian)"

FIGURE 4 | The chute where livestock are sprayed once a week with insecticide to prevent nuisance insects. Copyright © Christina Lunner-Kolstrup.

The most important topic mentioned by the interviewees was the use of chemicals and drugs on livestock. Once a week, the farmers gathered the animals and drove them through a chute (**Figure 4**). They sprayed them with insecticide, using a backpack or hand sprayer, to prevent ticks, lice, tsetse flies, and other biting nuisance flies and infections caused by these insects [such as East Coast Fever, Bovine Babesiosis (also called Redwater or Tick Fever) and Anaplasmosis (also called Gall Sickness)]. The insecticide used for spraying the animals was bought in the local veterinary drugstore, but this store was seldom run by a veterinarian. The regulations on providing chemicals and drugs for both humans and animals have been delegated to the private sector by the Ugandan government and no prior education or training is required for selling drugs or opening a drug store.

> "One I know was working in the service commission and when he left, he went into dealing agrochemicals. But he didn't have any prior training in dealing drugs; the law is not embracing, the policies are there but not implemented – it is lacking and the public service doesn't regulate the private sector (Dairy farmer)"

The storekeeper often has limited or no knowledge and gives no information to the farmers about the chemicals or drugs except for dosage. Furthermore, the labels on medicine packaging were small and the farmers interviewed did not understand the text or relate to the warning signs given on the labels.

> "They give you simple instructions on how to mix and how to apply – but not how to protect yourself (Dairy farmer, translated)"

Another critical problem identified was that several farmers in the region were illiterate and would have needed visual information or practical training and instructions. Spraying was conducted without the use of PPE such as face masks, overalls (except for the large dairy farm), eye goggles, gloves, or rubber boots. Those interviewees who were aware of the existence of PPE considered it too difficult to use, too expensive, and difficult to obtain. The farmers explained that they usually felt unwell, dizzy, vomited, and had pain and a burning feeling in the face and eyes after spraying their animals. The symptoms of poisoning lasted from a couple of hours to several days. The farmers used indigenous medical herbs, showered, or rested for some hours until the symptoms had disappeared. However, the symptoms could be so severe that they needed treatment and bought medication at the local drugstore without a medical prescription or seeing a medical doctor.

In order to maintain good health and avoid getting sick, the participants stated the importance of eating well and relying on local indigenous food (meaning without pesticides). They seldom fell sick and if they did, it was just local diseases and fever. Fever, coughing, and diarrhea are common among Ugandan farmers and are often related to malaria, tuberculosis, Salmonella, Q-fever, leptospirosis, or brucellosis (zoonotic disease where humans are infected through, e.g., consuming unpasteurized milk). Almost all the interviewees were unaware that some diseases could be transmitted from animal to human and vice versa; they did not know of brucellosis, typhoid, or Salmonella, just diarrhea, fever, or a simple cough.

The dairy farmers seldom visited the medical clinic (too expensive, no trust in medical experts, and too far away). If they had a fever, they sometimes bought medicine in the local drug store. This raised the sensitive topic of farmers using animal medicine for human treatment.

> "Here I am (as the farmer), I've been growing up with this animal, it falls sick, it gets a fever (we call it fever), it's given medicine and it heals – so, I have a fever, I can share the drug. They just reduce the dose! So many mills – 5 mills (millilitre) for an animal and 2 mills for a human! (The veterinarian explained the reasoning among farmers)"

Benefits of a Healthy and Safe Farm Environment

The female dairy farmer was a progressive farmer and viewed her farm as a business. She stated that a healthy and safe environment for animals and humans would result in profitable production and healthy and happy workers. She had developed routines for milking, hygiene, animal handling, feeding, animal book keeping, use of chemicals, and human safety. The female dairy farmer provided training for her employees and other neighboring farmers on how to deworm the cattle and information concerning the time restriction for using meat and milk after treatment. She viewed employees as a resource and had a great interest in employee management and how to recruit, train, and retain skilled farm workers. She took good care of her employees; she trained them how to manage dairy cows and keep records, gave them fair wages, housing conditions, and access to medical care, and believed that managing the human capital on her farm is very important and necessary for her survival as a farmer. In addition, she chose to employ labor instead of investing in technical equipment.

> "I'm not really keen on mechanising because we have the human resource everywhere and I could just as well employ as many (workers) as possible, so that they also can earn their livelihood from here (Dairy farmer)"

Availability and Demand for Health and Safety Education

Information and practical training on agricultural health and safety in the region were non-existent. Almost all interviewees were eager to gain knowledge and attend training on how to identify and handle risks in order to prevent diseases and injuries when working in the fields and with livestock. The farmers had confidence in non-government organizations (NGOs) and veterinarians and preferred them, in collaboration with agricultural health and safety specialists, to hand out information and conduct practical training courses. The dairy farmers also mentioned the urgent need for simple safety aid kits and PPE, such as face masks and gloves. However, one of the farmers commented on the need for practical training regarding PPE:

> "You need to show them (the farmers), not just explain, the importance of using them (PPE), otherwise you will just give it to them and they will not use it. You need to show them the associated risks and dangers on the farm, show them how to use it (PPE) and then you can provide it (Dairy farmer, translated)"

DISCUSSION

Level of Knowledge and Awareness

The results obtained in this study indicate that the dairy farmers interviewed had low knowledge and awareness of risk factors and health and safety issues relating to dairy farming. They experienced physically demanding and hazardous work tasks related to working with their livestock and farm work in general, which jeopardized their safety and health. These results are consistent with findings in previous research studies and reviews among farmers in Africa (21–27). Cuts and bruises, both severe and less severe, were often treated at home or by a neighbor with specific knowledge of healing herbs. The farmers did not consider these injuries worthwhile noting, reporting, or seeking medical care for. The farmers seldom visited medical clinics, probably because of low convenience, being too geographically remote, lack of access to transportation, lack of financial means to pay a medical doctor, lack of confidence in the medical services, or lack of adequate and available health care.

A systematic occupational health and safety study conducted in Gambia showed that farmers were exposed to a number of risk factors which seriously affected their health (23). This study also comprised extension workers and the results showed discrepancies regarding the comprehension and severity of injuries, indicating under-reporting among farmers. Under-reporting might also have occurred in this study, but for different reasons. Farmers and ruralists in developing countries face poverty (39) and conduct farming as the only option for obtaining their daily livelihood, and therefore they may be more prone or have no other choice than to accept hazards and injuries as part of their occupation. A number of factors, such as weather, drought, hurrying to complete work tasks in rain-fed agriculture with two short rain seasons, and uncertainty about profitable crop harvests and livestock yields, put farmers in a state of anxiety, and they may be more vulnerable to injuries and perhaps even mental strain (22).

Under-reporting is probably attributable to a low level of knowledge and awareness concerning the hazards in dairy farming and how it could affect farmers' health and safety. Information or practical training on prevention of injuries and diseases relating to dairy farming or agriculture in general was not available to the interviewees, but earnestly requested, as the region relies heavily on crop and livestock production. Most of the farmers interviewed were illiterate, which is not uncommon in many developing countries (40), and they had learned farming practices from elder peers. It is a major challenge to provide information and practical training to increase knowledge and awareness about health and safety that is adapted to the educational level of these farmers. This challenge of developing appropriate, participatory, and practice-based courses has also been acknowledged in other studies (41, 42).

Use of Agrochemicals on Livestock Jeopardizes Human Health and Safety

The most problematic issue identified was the use of agrochemicals and drugs in livestock production. Illiterate farmers handling dangerous agrochemicals, without proper instructions and PPE, face an increased risk of allergic or irritant skin reactions and acute and chronic intoxication. Besides directly affecting farmers' health through dermal contact or inhalation, misuse of agrochemicals also poses a health risk in terms of milk contamination. This is a serious food safety problem for milk consumers, especially if no time restriction is applied after treatment. Several residues of acaricides and pesticides have been found in cow's milk in developing countries (25, 43, 44). The use of agrochemicals and drugs was reported to be associated with insufficient information from the drugstore or on packaging and misuse of medication due to ignorance.

The farmers in Western Uganda are mainly pastoralists and are dependent on high milk yield as one of their main protein sources. In order to boost milk production, crossbreeding between local cattle and imported high-yielding Holstein Friesians cattle is common. These crossbreeds have lower susceptibility and resistance to local diseases and require antibiotics, anti-parasitic drugs, and intensive tick protection to survive. Without such treatment, there is not only a threat to animal health and a risk of heavy losses of livestock but also a threat to human health (25). Consequently, comparative studies have shown that cattle crossbreeds in African countries are treated with acaricides (pesticides that exterminate members of the arachnid subclass Acari, which includes ticks and mites) up to twice a week and the user often employs no form of quality control or restriction (25).

The farmers interviewed in this study used insecticides for spraying animals to protect them from insects and parasitic diseases. This was done with old inefficient sprayers, with liquid probably leaking and dropping on the farmers' skin through soaking clothes. Studies have shown that overdosing is erroneously believed by farmers to enhance the effect, but instead it increases the risk of exposure and poisoning because of misuse (26). The farmers interviewed did not use PPE in most cases, and in general, PPE use is uncommon in the region, due to lack of availability, comfort, and affordability, as reported previously for other African countries (23, 26, 27, 45, 46). The farmers interviewed here reported body symptoms of pesticide poisoning with a duration which varied from hours to several days. Unfortunately, a number of the agrochemicals available in many developing countries are banned, unregistered, outdated, and unlabeled pesticides sold uncontrolled and without restrictions at local markets or small shops by illiterate or ignorant vendors (25–27). Lack of legislation and enforcement regarding PPE and sale of agrochemicals has also been demonstrated in other studies (23, 27). According to the interviewees and studies in other developing countries, fake, substandard, and diluted drugs are common (25). The pesticides used by the farmers in this study were labeled but, unlike in a similar study conducted among farmers in Gambia (27), the farmers in this study did not understand or relate to the symbols and warning signs on the packaging. This means that information and instructions need to be adapted to users and their language and culture.

Animal Drugs Used for Human Treatment

The veterinarian interviewed raised the issue of use of animal drugs for human treatment. This was not mentioned by the farmers, which according to the veterinarian and the Ugandan coauthor could be because the farmers could not distinguish between human or animal drugs, or because of taboo and shame. Use of animal drugs for human purposes has been reported previously in a study among Gambian farmers (27), where 81% knew of farmers and field workers using pesticides for non-agricultural purposes (27).

Zoonotic Diseases a Serious Health Risk

Cultural and religious beliefs may play an important role concerning zoonotic diseases. The farmers interviewed were unaware of zoonotic diseases and found it difficult or impossible to imagine or comprehend that they could get diseases from their animals. In a study among Gambian farmers, headache (35%) and chronic cough (21%) were frequently reported, and, as in this study, awareness of zoonotic diseases and other diseases relating to agriculture was absent (23).

East Africa has a high zoonotic burden (25, 28) and infectious diseases relating to agriculture are playing an increasing role (28, 47). In developed countries, 20% of human illness and fatalities are attributable to zoonotic diseases and one can only imagine the scope and severity in developing countries (28). Several studies have shown that zoonotic diseases are a key concern in developing countries and show a strong association with poverty, hunger, and livestock production (28). Furthermore, the rural population, including farmers, in developing countries is vulnerable, as inadequate diet and exposure to endemic and occupational diseases, in combination with poor sanitation, inadequate housing, malnutrition, and various parasitic and bacterial infections, have been shown to constitute a vast risk concerning health (39). A possible intervention in order to prevent infections and zoonotic diseases and to improve the health status could be vaccination of the farm population. Availability and offering chemoprophylactic medication could also be an option, but could carry an associated risk of medical resistance, e.g., to antibiotics and anti-malarials.

Strategies for Health and Safety Improvements

Agriculture, a major driver in Ugandan economy (48), could be expected to generate government interest and concern for the health and safety of its producers (farmers, agricultural workers, and their families). Investment in occupational health and safety would add value to the country by resulting in improved working conditions, higher labor productivity, and a healthier farm population. One way to increase awareness and knowledge could be by comprehensive campaigns in rural areas providing educational and illustrative information and participatory practical training courses in the local language. These measures need to be implemented in interdisciplinary and participatory collaboration between NGOs, veterinarians, medical doctors, farmers, and role models (like the well-educated female farmer interviewed here). More importantly, farmers must trust their educators, and training must be performed with respect to the cultural and religious beliefs and norms of the region.

In Mali, special field schools in a community of cotton growers trained farmers in alternative methods of pest control and succeeded in nearly eliminating the use of toxic pesticides (42). In Gambia, researchers found that a community-based participatory approach and cultural acceptance were essential for successful implementation of interventions to improve health, safety, and productivity among smallholder female farmers (41).

Furthermore, simple PPE solutions should be introduced, such as long sleeves and trousers, boots, gloves, and facial masks, and information concerning personal hygiene (washing clothes and showering after pesticide use) when applying agrochemicals. Moreover, enforcement, monitoring, inspection, and education of vendors of agrochemicals and medical drugs should be prioritized and implemented in order to reduce uncontrolled sales by unknowledgeable vendors.

Study Limitations

The study comprised a small sample of Ugandan farmers and farm workers (six interviewees on four farms and one interview with a veterinarian) in a region with high livestock density. In order to find farmers who would agree to be interviewed and willing to share experiences, we chose sample selection by convenience using local contacts to identify dairy farmers in the region. Based on the limited data material, we cannot claim that the results are representative for all Ugandan dairy farmers. However, the intention was not to generalize, but to explore and highlight important occupational health and safety issues for individual dairy farmers. The farmers mentioned many of the same issues and the last interview did not bring new information to the material, meaning that saturation had been reached. Furthermore, our main findings are supported by other occupational health and safety studies conducted in Africa, which also contributes to the credibility of the study.

Culture and language barriers can be a limitation, but this study was a cross-country collaboration, which was a strength. Both authors were present at all interviews and the university colleague from Uganda Martyrs University, who specializes in agriculture and is familiar with the local culture and language, performed the interviews in the local language. Furthermore, interpretation of the collected material and discussion of results were performed by both authors, in order to reduce the bias of cultural and language barriers. Over- or under-reporting of incidents could have affected the results. Lack of awareness and knowledge of occupational health and safety indicates the likelihood of under-reporting, and thus the topic is of immense importance to address. Several of the farmers were illiterate and, therefore, interviews were chosen as a suitable method. The use of interviews also provided the possibility for explaining and asking sub-questions. The farmers interviewed sometimes had difficulties understanding the health and safety concepts, but as the Ugandan colleague is familiar with the field of occupational health and safety, the culture and the local language, he was able to explain matters to the farmers. The use of interviews as a method limited the generalizability of the findings, but increased the possibility of obtaining a rich picture and a more profound understanding of the issues.

CONCLUSION

Studies that can lead to improved human health, safety, sustainable development, poverty reduction, a fair livelihood for farm populations, and gender equality in low income countries can provide various benefits for individuals and for the community and the country at large. The results obtained in this study indicate that the level of knowledge and awareness of agricultural health and safety risks, disease, and injury prevention among the Ugandan dairy farmers interviewed was low. The farmers mentioned few agriculture-related complaints, injuries, or diseases except poisoning from using agrochemicals. Training on health and safety in agriculture is urgently needed in the region of the farmers interviewed. The study also highlights some of the key issues to be addressed in future research such as the zoonotic burden, the use of animal drugs for human treatment, limited use of PPE, education of agrochemical strategies retailers, and the need for participatory approaches for successful implementation of health and safety prevention. This study comprised few dairy farmers and makes generalization not possible. However, the results are supported by other research studies implying that the findings in this study most likely mirror the situation among farmers in other developing countries.

AUTHOR CONTRIBUTIONS

CK developed the research idea, applied for funding, designed the project, performed the literature review, collected and analyzed data, and wrote most of the manuscript. TS participated in planning the interviews, selected the interviewees, translated from the local language to English, and participated in interpreting the results and writing the manuscript. Both authors revised the manuscript and approved the final draft.

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The Roles of Financial Threat, Social Support, Work Stress, and Mental Distress in Dairy Farmers' Expectations of Injury

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Farming is dangerous, with fatalities among the highest in any occupation. Farmers often work alone, for long hours, with unreliable equipment and in difficult weather conditions with hazardous chemicals and livestock. In addition, farmers make large financial commitments exposing them to high levels of financial risk. Exposure to such financial risk can give rise to subjective experiences of financial threat (FT) that are psychologically challenging. The current study attempted to characterize the role that FT plays in farm injuries. One hundred and twenty one dairy farmers completed a battery of questionnaires assessing FT, social support (SS), depression, anxiety, farm job stress, and health and safety beliefs. Mental distress directly predicted farmers' expectations of injury and a direct effect of non-financial farm stress (FS) approached significance. Mental distress mediated these relationships as evidenced by significant indirect effects of FS and FT, and SS served to reduce distress. These findings support calls for interventions designed to reduce FS and FT and increase SS for farmers.

Keywords: farming, dairy, injury, mental health, financial threat

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INTRODUCTION

Farming is one of the most dangerous occupation in Ireland (1) and worldwide (2); with fatalities five times higher than construction, with self-employed or family farmers at significantly increased risk. In Ireland, 30 people were killed in farm-related incidents in 2014, a rise of 87% from the previous year, and these deaths accounted for ~55% of all the work related deaths that year. According to the International Labor Office (2), of ~335,000 workplace fatalities every year, 170,000 (over 50%) are in agriculture. In order to help develop policy and personal interventions reduce farm accidents, the current study sought to assess psychological factors that influence farmers' expectations of injury. In light of recent market changes, the study focused in particular on the effects of financial threat (FT) on Irish dairy farmers.

Among farmers, dairy farmers are of the groups most at risk from workplace accidents. In Ireland, dairy farmers are over-represented in farming fatalities. According to McNamara (3), 58% of Irish farming fatalities in the period 2000–2007 took place on dairy farms, while dairy farms constitute ~11.2% of farms (4). Dairy farming is conducted on 15,600 farms in Ireland, and the average farm size is 55.9 ha with 76.4% within the 30–99 ha range. In terms of economic activity, dairy farms are 3.75 times larger than the average farm (4). Dairy farms are highly capital intensive deploying on average €0.98 million worth of assets comprised of land and buildings (85.6%), livestock (7.2%), machinery (4.9%), and trading assets [2.3%; (5)]. Despite their economic size, the average labor units deployed on dairy farms is estimated at 1.59 labor units, with 85.5% being farm family, principally the farm operator, who provide an estimated 57% of total labor (6).

Stress (both physical and psychological) is a strong predictor of farm injury and resulting safety behaviors (7), as well being a connector between financial problems and injury in farming (8). A number of features of dairy farming expose these farmers to greater financial instability and potential stress than farmers in other sectors. First, the constant work commitment associated with milking production constitutes a consistent burden (9). Second, dairy farmers have greater exposure to uncontrollable external factors, such as the weather, sick animals, government policy, and the economy (10). Finally, in recent years, dairy farmers have faced high levels of financial instability (11).

For Irish dairy farmers, changes in the financial stability of the milk price have lead to greater price uncertainty for farmers. Since 2008, a series of protections that were in place to protect milk price from lower price competition from outside Europe have been progressively removed leading to increased volatility in the milk price. For the period 1993–2006, French and Shalloo (12) demonstrated that the milk price was relatively stable, at 17% change across the 13-year period, but, in the following period, 2007–2015, there was considerable variability (91%; from 22 to 42 cent per liter) in milk price (13). The removal of the EU milk quota system in 2015 also has had implications for farmers' financial stability. In 1984, EU policy set a pan-European limit on milk production using a milk quota to limit surplus production (14). Each EU country was allocated a national quota to be divided among dairy farmers. Farmers who exceeded quota in a production year were required to pay a national levy. The effects of the quota on dairy farming in Ireland were manifold and complex (15). However, in April 2015, the EU milk quota system was removed. The removal of the quota has potential positive and negative effects. The dairy quota system was intended to provide price and supply stability by limiting production, but these market-distorting restrictions on production had negative effects, such as dumping of excess milk. The removal of the quota, and associated price supports, therefore, constituted an opportunity for greater earnings through increased production, but also there was concern that greater exposure to world market conditions would lead to significant falls in the price obtained for milk. Thus, the downside of the removal of the quota is potential increased price instability for dairy farmers (i.e., they were less sure how much their milk would sell for) and increased financial uncertainty.

Nearly 25% of farmers report financial problems and nearly 80% are most worried about money (16). Melberg (17) identified the main stressors among farmers as: their evaluation of the state of the household economy, presence of unsafe working conditions, injury, ill–health, or disability. High reported levels of stress and stress symptoms (combined with low engagement with safety behaviors) have been shown to predict potential risk of injury in farmers (18). Farmers (aged 55–60 years old) were found to report high emotional stress and mental ill-health in relation to health and safety needs (19), with a significant relationship found between self-reported stress and injury. In particular, exposure to high levels of financial uncertainty may induce subjective experiences of FT that are psychologically challenging but, to date, there is little research that specifically addresses these issue in the farming community.

The job demands-resources model [JDR; (20)] provides a useful descriptive framework for conceptualizing the effects of workplace stress on farmers. It has been supported in many studies across different job contexts (21). The core principle of the theory is that job demands can incur psychosocial and physical costs, but job resources trigger motivation processes that lead to greater work engagement and performance and that can offset the costs incurred by job demands (22). As self-employed lone workers, farmers have fewer resources, both practical and psychological, to deal with negative workplace situations than the average worker. In terms of demands, farmers are exposed to higher levels of stress and the effects of such stress are observed in negative physical and mental health outcomes. Previous studies relating the JDR model to safety at work found that the effects of job resources and job demands on safety outcomes were mediated by emotional exhaustion, such that greater resources protected against emotional exhaustion, which was associated with better safety outcomes, while higher demands increased emotional exhaustion, which led to more negative safety outcomes (23).

An individual's mental health constitutes an indicator of the psychological resources that he or she can employ at work. In line with the foregoing theoretical position, reduced mental health should predict injury and a number of studies have, in fact, demonstrated an association between mental health and occupational injury in farming (24) and other industries (25, 26). Male farmers have been found to have higher levels of anxiety and depression compared with matched controls (27, 28). Farmers have higher incidence rates of suicide and psychological distress, and lower use of health services that provide support for those with mental ill-health (29, 30). Depression is associated with injury in farming (31) and those farmers who suffer with depression are more likely to experience injury and less likely to engage in safety behaviors when farming injury (32) leaving them susceptible to injury. Anxiety and depression have been associated with impaired work performance and safety (33).

Traditionally, an important source of resources for the farmer has been the informal networks of farmers and other social supports (SSs) at home and in the local community. Economic, physical, and psychological supports were provided in this way. In relation to mental health, SS has been found as the most important predictor of subjective wellbeing for men in rural communities (34), as SS is beneficial to farmers' mental health (35). It works as a protective factor, reducing the probability and severity of mental health problems (36). A farmer's level of SS has been shown to affect the level of risky behaviors (such as operating without safety equipment) the farmer is willing to engage in (32). SS may act as a "buffer" against the negative effects of stress, such as ill-mental health, for middle-aged males (37). Farmers' mental health seems to be moderately protected by being in a relationship or having someone to consult (38). Finally, spousal support has been found to protect farmers from stress; buffering the effects of economic pressure on the men that reduces depression (39) and protects against the incidence of anxiety (40).

Dairy farmers are exposed to a range of potential stressors. Of particular interest, in the current study, were the effects that financial worries may have on mental health and farmers' health and safety behaviors. As a measure of health and safety behaviors, we focused on farmers' expectations of injury. In line with the foregoing theories, we hypothesized that mental health may mediate the effects of FT and FS on susceptibility to injury. Strong mental health may function to reduce the impact and effect of financial worries and other stressors on injury expectations; possibly buffering the effect of stress on behavior by using mental resources to deal with the negative effects of stress (41). Conversely, FT and FS may cause mental distress (i.e., reduced mental health), which reduces the resources available to the farmer to engage in safe behavior and increase injury expectations. SS, on the other hand, increases available resources, decreasing mental distress and injury expectations. To summarize, the current study assessed the negative effects of FS and financial worries and the positive effects of SS on self-reported injury expectations and assessed whether these effects were mediated by mental distress.

MATERIALS AND METHODS

Participants

All participants were active farming men ($n = 121$) ranging in age from 18 to 80. The 45- to 54-year-old group (33.9%, $n = 41$) was the most common age category. Participants' ethnicity comprised Euro-Caucasian ($n = 121$). Exclusion criteria included female farmers; farmers who rented and did not own farms; farmers not from Ireland (non-national farmers), and if farmers were below 18 years old or above 80 years old. Female participants were excluded as data indicate that the majority of dairy farmers are recognized as male (31) and it would have been difficult to balance the gender ratio. Farmers renting out land do not have the same personal financial liability as farmers who own their land, and so they were excluded. Farmers originally from outside Ireland were excluded too, since they may have had alternative training and knowledge of health and safety in farming from those originating in Ireland. Ages outside of 18–80 cohort may have had additional influences that confounded the effect of the variables on the dependent variable, such as health issues or the effects of old age, on farming abilities and so they were excluded.

Relevant details of participants are provided in **Table 1**. In summary, the farmers surveyed constituted a relatively well-resourced and well-supported group, who were accessing government assistance with a view to expansion due to the removal of the CAP and quota restrictions for dairy farming in 2015. The majority of participants had farms of >120 acres (59.5%, $n = 72$). Three quarters of participants had completed at least secondary level education (76.0%, $n = 92$). Overall, the majority of participants were married (72.7%, $n = 88$), attended Teagasc (the Irish Agriculture and Food Development Authority) meetings at least "often" (70.2%, $n = 85$) and identified as specialist dairy type of farmer (66.9%, $n = 81$) or mixed dairy (dairy and cattle) (25.6%, $n = 31$). Most participants' farms (95%, $n = 115$) were on a trend of expansion, having recently expanded, currently expanding or planning expansion within the next 3 years. Many participants reported incomes of over €80,000 in the past 3 years (34.7%, $n = 42$), but debt was bimodally distributed with a large proportion of participants reporting <€50,000 debt on their farms at the time of the study (42.1%, $n = 51$), and a similar proportion reporting in excess of €200,000 debt on their farms (37.2%, $n = 45$).

The sample was recruited during attendance at Teagasc farm meetings in various locations all over the Republic of Ireland: Galway, Mayo, Roscommon, Kilkenny, and Waterford. The sample was achieved by convenience sampling through recruitment. Consequently, farmers in this group were arguably better resourced than the average dairy farmer in Ireland. Response rates for participation were fair: 300 study packs were sent out and 122 returned, which was an acceptable reliable response rate

TABLE 1 | Demographic information of participants in the current study.

Age	<35 24 (19.8%)	35–44 21 (17.4%)	45–54 41 (33.9%)	55–64 22 (18.2%)	>65 3 (2.5%)	Missing 10 (8.3%)
Marital status	Single 25 (20.8%)	Married 88 (73.3%)	Separated 2 (1.7%)	Divorced 1 (0.8%)		4 (3.3%)
Education (ISCED 2011*)	Did not complete upper secondary school 25 (20.7%)	Completed upper secondary education 29 (24%)	Experienced tertiary level education 28 (23.1%)	Completed short-cycle tertiary education 10 (8.3%)	Completed bachelor level or higher 25 (20.7%)	4 (3.3%)
Farm size (acres)	<50 2 (1.7%)	51–70 9 (7.4%)	71–90 9 (7.4%)	91–120 25 (20.7%)	>120 72 (59.5%)	4 (3.3%)
Type of farming	Dairy mixed 31 (25.6%)	Specialist dairy 81 (66.9%)	Other 6 (5%)			3 (2.5%)
Future farm direction	Expanded farm in last 3 years 37 (30.6%)	Expanding farm now 49 (40.5%)	Expanding farm plan in next 3 years 24 (19.8%)	Contracted farm in last 3 years or plan to in next 3 years 6 (5%)		5 (4.1%)
Attendance at Teagasc meetings	Never 5 (4.1%)	Rarely 8 (6.6%)	Sometimes 19 (15.7%)	Often 59 (48.8%)	Always 26 (21.5%)	4 (3.3%)

**Education level is described using the levels from the International Standardized Classification of Education (2011).*

for the participants solicited [40.66%, $n = 122$; (42)]. The study was incentivized by a €100 fuel voucher that could be won by any individual who took part and returned a fuel draw letter. The individuals would be entered into a draw and the winner would be posted out the prize upon being selected. Further demographic information is displayed in **Table 1**.

Measures

The current study employed a correlational design and measured six variables. Farmer's Expectations of Injury (FEI) constituted the outcome variable and it was estimated using the "susceptibility to a farm-related accident/illness" factor of the Farm Safety and Health Beliefs Scale. Five predictors of FEI were measured: FT, FS, SS, depression, and anxiety. Based on the JDR model, FT, Farm job stress, and SS constituted measures of available resources. Depression and anxiety were included as potential mediators of the effects of these variables on Expectations of injury. FT was measured using the Financial Threat Scale (FTS), FS, using the Edinburgh Farming Stress Inventory (EFSI), and SS, using the Multidimensional Scale of Perceived Social Support (MSPSS). Depression was measured using the Patient Health Questionnaire (PHQ-8) and anxiety, using the Generalized Anxiety Disorder Assessment (GAD 7).

Outcome Variable – Farmers' Expectations of Injury

In order to assess FEI, the "susceptibility to a farm-related accident/illness" factor was extracted from the Farm Safety and Health Beliefs Scale (43). The susceptibility to a farm-related accident/illness factor has established reliability (43) and reliability was confirmed in this study also (Cronbach's $\alpha = 73$). The FSHBS scale is derived from the Health Beliefs Model (44) of health and safety behaviors and includes five factors: (i) susceptibility to a farm-related accident/illness, (ii) benefits of performing safety and health behaviors; (iii) barriers to performing these behaviors; (iv) self-efficacy regarding performing these behaviors; and (v) severity/finances regarding the consequences of an accident/illness. The Susceptibility to a farm-related accident/illness factor includes six items that address the likelihood of injury on the farm (e.g., "*I'm more likely than the average farmer to have a farm-related accident or illness*"). For each statement, participants responded on a five-point scale ranging from 1 (*strongly disagree*) to 5 (*strongly agree*). There was a sixth option that represented an unknown response to the question from the participant *N/A* (*not applicable)*. Participants completed the entire FSHBS scale, which consisted of 39 items.

First-Order Predictors

Financial Threat

The FT experienced by the farmers was assessed by using the FTS (45). The FTS has an established reliability (Cronbach's $\alpha = 0.89$). The FTS was developed based on existing threat measures and threat research to assess hypothesized FT. The items include areas related to (i) risk of threat (e.g., "*How much do you feel at risk?*"); (ii) worry related to threat; (iii) anticipated threat; (iv) mental fixation on individual personal finances, and (v) uncertainty about threat. For each item, participants responded on a five-point scale ranging from 1 (*Not at all*) to 5 (*Extremely*) indicating the accuracy of statements reflecting their personal feelings about FTs they were currently facing. Participants completed the entire FTS scale, which consisted of five items.

Social Support

Social support was assessed by using the MSPSS (46). The MSPSS has an established reliability (Cronbach's $\alpha = 0.88$) is a brief and simple tool to use to establish the level of SS that the respondent identifies that they have. The scale was designed to assess the perceptions of SS; identified by the respondent answering questions relating to family, friends, and significant others (e.g. "*There is a special person around when I am need*"; "*I have friends with whom I can share my joys and sorrows*"; "*My family is willing to help me make decisions*"). For each question, participants responded on a seven-point scale ranging from 1 (*Very strongly disagree*) to 7 (*Very strongly agree*), indicating which statements were most representative of how much SS they felt they had, indicating their personal level of perceived SS. Participants completed the entire MSPSS scale, consisting of 12 items. Due to the small sample size, SS was included as one variable in the correlational analyses; so all items were summed to approximate a generic SS construct.

Farm Stress

Farm stress was assessed by using the EFSI (9). The EFSI has an established reliability (9) and reliability was confirmed in this study also (Cronbach's $\alpha = 0.93$). This inventory assess domains that are pertinent to farming lives and may be sources of added stress to the profession including (i) time pressure (e.g., "*Too much to do and too little time to do it*", (ii) finance (e.g., "*Debt load*"), (iii) geographical isolation (e.g., "*Feeling isolated on the farm*"), (iv) hazards in farming (e.g., "*Farming related accidents*"), (v) government policy (e.g., "*Complying with environmental regulations*"), and (vi) unpredictable factors in farming (e.g., "*Bad weather*"). Answers are scored by the indicated response to a stem question "*How severe is the stress caused by this?*" For each question, participants respond on a five-point scale ranging from 1 (*None*) to 5 (*Very Severe*) indicating how each of the events and situations represented a potential source of farming-related stress and how severe the stress caused by these events/situations was when farming. Participants completed the entire adapted EFSI, consisting of 27 items. Due to the small sample size, FS was included as one variable, so all items were summed to approximate a generic FS construct.

Mediator – Mental Distress

In the current study, it was hypothesized that the effects of FT, SS, and FS on FEI are mediated by mental distress. To provide a measure of mental distress, we estimated the levels of depression and anxiety in our sample and used these variables to create a latent variable termed mental distress.

Depression

Depression levels of the farmers were assessed using The Patient Health Questionnaire (PHQ-8) (47). The PHQ-8 is a shortened form the PHQ-9, which has been employed for population studies (48). The PHQ-9 has established reliability (Cronbach's $\alpha = 0.84$) and uses a criteria-based diagnosis of depression using a shortened item scale, which can be self-administered. The questionnaire is made up of nine items and major depression is indicated if five or more of the nine symptoms have been present in previous 2 weeks. Other levels of depression are established if two, three, or four of the depressive symptoms have been present. The questions are related to specific symptoms that a person may be experiencing related to depressive feelings at any given time during the previous 2 weeks (e.g., "*Feeling down, depressed, or hopeless*" and "*Feeling bad about yourself – or that you are a failure or have let yourself or your family down*"). For each question, participants responded on a four-point scale ranging from 1 (*Not at all*) to 4 (*Nearly every day*).

In the PHQ-8, the ninth item of the PHQ-9, which refers to thoughts of suicide or self-harm, is removed. In the current study, we deployed the entire PHQ-9 scale, because we wished to include such symptoms and remove such symptoms can reduce the sensitivity of the scale at the high end (49). However, 25 participants refused to complete this item. Consequently, we employed the PHQ-8 score, which consists of eight items, with depression scores ranging from 0 to 24.

Anxiety

The anxiety levels of the farmers were assessed using the GAD 7 (50). The GAD 7 has an established reliability (Cronbach's $\alpha = 0.92$, 2006) and is a useful tool for identifying possible GAD with questions that inquire about the anxiety felt by the respondent in the past 2 weeks. The GAD 7 assesses the severity of the anxiety with specific questions related to worry (e.g., "*worrying about different things*") and fear (e.g., "*feeling afraid as if something terrible might happen*") and the inability to relax (e.g., "*trouble relaxing*") and the effect it has had on the daily life. GAD is established if symptoms appear more often than once a week. Each answer given is accumulated to result in a score that places the respondent in the mild, moderate, or severe GAD category. For each question, participants responded on a four-point scale ranging from 1 (*Not at all*) to 4 (*Nearly every day*). Participants completed the entire GAD 7 scale, consisting of seven items.

Procedure

The National University Ireland, Galway Research Ethics Committee assessed and approved the study procedures with written informed consent from all subjects. All subjects gave written informed consent in accordance with the Declaration of Helsinki. The study was advertised by "word of mouth" by Teagasc dairy farming group leaders at regional centers across Ireland. Data were collected from 31st March 2015 to 31st July 2015 (4 months). All responses were verified for validity by sending study packs to the advisors directly for the dairy farmers they met with or when the researcher went to meet dairy farmers and hand out the study packs at the Teagasc meetings. Data were collected by return post with study packs handed out with a prepaid return envelope for all participants.

Data Analysis

In the current study, we were particularly interested in relationships among our predictors and in assessing the role that mental distress plays in mediating the effects of these predictors of FEI. In other words, we hypothesized that FS and FT influence FEI and that, to some degree, this influence occurs because they cause mental distress, and SS influences FEI because it reduces mental distress. To assess these effects, structural equation modeling was employed. Structural equation modeling refers to a set of statistical methods that allow estimation of direct and indirect relationships between observed variables and latent (inferred) variables (51). In the current study, structural equation modeling was employed to estimate the effects of FS, FT, and SS on self-reported injury expectation (FEI). It was expected that these variables would affect self-reported injury expectation, but that these effects would be at least partially mediated by the effects of these variables on mental distress, a latent variable derived from measures of anxiety and depression. That is, to some degree, FS and FT increase farmers' mental distress, but this is attenuated by SS, and increases in mental distress predict greater expectations of injury (FEI).

RESULTS

Descriptive Analysis

Table 2 provides the means and SDs of the measured variables and Pearson correlations between the variables. Three variables,

TABLE 2 | Means and SDs of the measured variables (leftmost two columns) and Pearson correlations (*r*) between the observed variables (remaining columns).

Scale	Mean	SD	FT (L)	SS	FS	Anx (L)	Dep (L)
Financial threat (FT)	11.17	4.11		−0.247	0.384**	0.477***	0.438***
Social support (SS)	66.55	11.29			−0.354**	−0.4**	−0.347*
Farm stress (FS)	66.68	17.76				0.463***	0.452***
Anxiety (Anx)	2.59	3.4					0.667***
Depression (Dep)	2.62	3.43					
Farm safety and health beliefs							
Susceptibility (FEI)	2.66	0.68	0.273	−0.075	0.384**	0.339*	0.285
Benefits	4.15	0.46	−0.181	0.261	−0.029	−0.159	−0.168
Barriers	2.86	0.74	0.307*	−0.288	0.5***	0.416**	0.439***
Self-efficacy	3.5	0.54	−0.319*	0.297	−0.445***	−0.364**	−0.285
Financial effects	3.29	0.78	0.232	−0.213	0.195	0.198	0.19

*Farmers' Expectations of Injury (FEI) were measured using the Susceptibility subscale of the Farm Safety and Health Beliefs scale (see Outcome Variable – Farmers' Expectations of Injury in section "Materials and Methods" for details). Variables followed by (L) were log transformed for analysis. Raw means and SDs are provided for these variables to facilitate interpretation. Asterisks denote significant effects (*p < 0.05, **p < 0.01, ***p < 0.001).*

FT, anxiety, and depression, were log transformed to correct for skewness and kurtosis. In all three cases, values were lower than expected, suggesting that the participants had low levels of these constructs. An additional benefit of log transforming the variables was that it made the measures more sensitive at the low end of the scale. Cronbach's alpha reliabilities of the predictor and mediator variables were above 0.8 in all cases (FT = 0.89, SS = 0.91, FS = 0.93, anxiety = 0.87, depression = 0.87) and Cronbach's alpha for FEI was.722.

In order to contextualize the relationships observed among the measured variables in the current study, details of the central tendency and other features of the distributions on these variables will be briefly discussed. FEI were measured using the Susceptibility scale of the Farm Safety and Health Beliefs scale. The scores obtained constituted means of the responses to six items on a likert scale from 1 (strongly disagree) to 5 (strongly agree). These items stated a vulnerability to a farm accident and so values above 3 indicated more agreement than disagreement with such statements and indexed farmers' perceived susceptibility to farm safety issues. The average score for all farmers was 2.66 (SD = 0.68) and 92 (77%) of farmers scored at 3 (neutral) or less. Even though this indicates that, on average, farmers did not feel vulnerable on their farms, 23% of farmers, reported values that indicated perceived vulnerability. In previous work, Hodne et al. (43) obtained a mean of 2.39 (SD = 0.54) for their sample, which was significantly less [t (191.17) = 4.1098, $p < 0.001$] than the average observed in the current study.

Financial threat ranged from 5 (the minimum possible) to 25 (maximum possible), and had an item level mean of 2.234, which was below the mid point of 3. This item level mean compared favorably with values obtained by Marjanovic et al. (45) (item mean: 2.74), suggesting that most farmers in the current study experienced lower FT than the standardization sample. However, three farmers reported FT scores of 20 or more indicating very high levels of financial worries. Mean FS was 66.68, which was close to the mean value of 68 reported by Deary et al. (9). The histogram in **Figure 1** summarizes data from the Edinburgh Farm Stress Survey (EFSS). The highest mean stress was reported due to Time pressure (3.0), followed by Bureaucracy (2.8). Slightly lower mean stress scores were observed in the areas of Financial worries (2.4), Unpredictability of the job (2.5), and Personal hazards (2.5). The lowest source of stress was Isolation (1.7).

Farmers in the current study scored highly in SS, with a mean of 66.55. The overall item mean score was 5.55, which is slightly less than that obtained by Zimet et al. (46) in the standardization sample (5.8). Typically, scores on the MSPSS are calculated separately from Family, Friends, and Significant Others, but in the current study, all items were summed to provide a generic measure of SS. Measured this way, SS can range from 7 to 84 and scores indicated that, on average, farmers experienced high levels of SS. Only 7 of the sample provided item means of <4, which indicated neutrality with regard to statements of SS, and 89 of the farmers had item means of 6 (strong agreement) or 7 (very strong agreement).

Scores on the mental health measures were quite low indicating low levels of mental distress. On the depression scale (PHQ-8), 93 (80%) of the farmers scored 4 or less, which constitutes minimal or no depression. This proportion is greater than the proportion in this category in the population sample (75.5%) recruited by Kroenke et al. (48). A similar proportion exhibiting minimal or no anxiety was obtained for the Anxiety

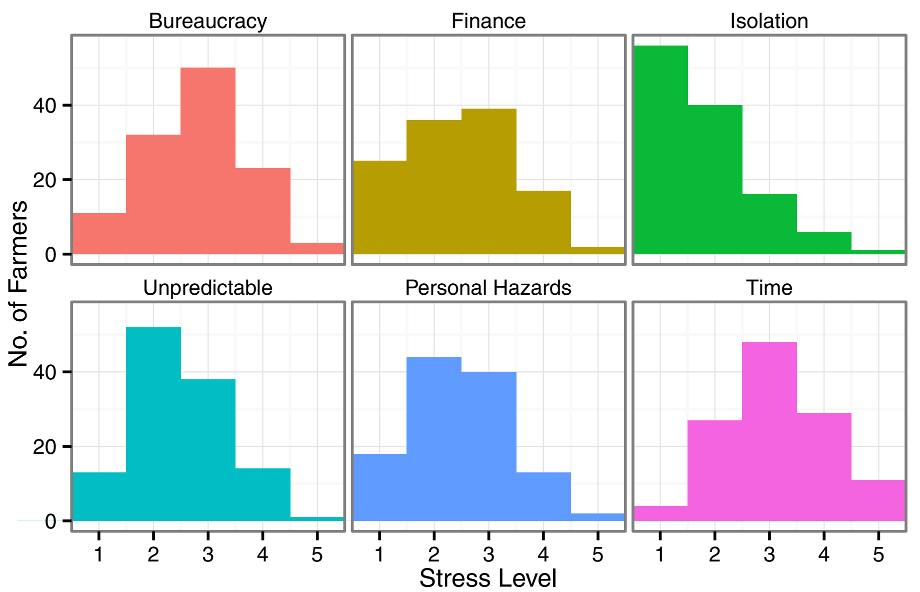

FIGURE 1 | Histogram of the values of stress level reported for each of the six areas of stress captured in the Edinburgh Farm Stress Survey. In each case, a score of 1 indicated "no stress" and a score of 5 indicated "very severe stress." The height of each bar denotes the number of respondents who expressed that level of stress in that stress area.

scale (GAD); 94 (81%) of the farmers scored 4 or less on the GAD, which was greater than the proportion in this category in a standard population sample [70.5%; (52)]. The suitability of these instruments for the current sample is considered in the discussion.

Demographic Variables

A series of analyses of variance were conducted to assess whether demographic variables impacted FEI. No significant effects were observed in any of these variables (Age: $F_{3,103} = 0.73$, $p = 0.54$; Marital Status: $F_{1,101} = 1.43$, $p = 0.23$; Education: $F_{3,101} = 1.09$, $p = 0.34$; Farm Size: $F_{3,110} = 0.07$, $p = 0.97$; Farm Type: $F_{1,109} = 1.94$, $p = 0.17$; Farm Expansion: $F_{2,106} = 1.63$, $p = 0.2$; Meeting Attendance: $F_{2,100} = 0.13$, $p = 0.88$).

In addition, two-way ANOVAs were conducted to assess the effects of Debt (Below 100k euros/Above 100k euros) and Annual Income (Below 60k euros/Above 60k euros) on FEI and FT. Neither Debt, $F(1,114) = 0.633$, $p > 0.05$, Income, $F(1,114) = 0.929$, $p > 0.05$, nor the interaction of these variables, $F(1,114) = 0.528$, $p > 0.05$, affected FEI. Similarly, neither Debt, $F(1,113) = 0.024$, $p > 0.05$, Income, $F(1,113) = 1.278$, $p = 0.261$, nor the interaction of these variables, $F(1,113) = 0.972$, $p > 0.05$, affected FT (log transformed) scores.

Correlations

The correlations in **Table 2** provide support for the hypothesized model of FEI. FEI was predicted by FS ($r = 0.384$, $p < 0.01$) and anxiety ($r = 0.339$, $p < 0.05$). Weaker non-significant relationships were observed between FT and FEI and between depression and FEI. There was no direct relationship between SS and FEI. The proposed mediators, anxiety and depression, were predicted by the relevant first-order predictors. Anxiety was predicted by FT, FS, and anxiety, and depression was also predicted by these three measures. There was also a strong correlation between anxiety and depression, as is commonly observed.

The five proposed predictors of FEI were included in a multiple linear regression to estimate the variance explained by a linear combination of these variables. The model was significant [$F(5, 96) = 5.462$] and accounted for 18.09% of variance in FEI. In this model, only the beta value for FS was significant ($b = 0.012$, SE = 0.004, $t = 2.880$, $p = 0.005$), which suggests a more complex structure in the relationships among the variables. The remaining beta values were as follows: FT ($b = 0.158$, SE = 0.187, $t = 0.841$, $p = 0.402$), SS ($b = 0.010$, SE = 0.007, $t = 1.468$, $p = 0.145$), anxiety ($b = 0.161$, SE = 0.107, $t = 1.498$, $p = 0.138$), depression ($b = 0.031$, SE = 0.106, $t = 0.296$, $p = 0.768$).

Structural Equation Model

As described previously, it was expected that FT, FS, and SS would impact FEI indirectly through the effects of these predictors on mental health. Following the regression analysis described above, it was apparent that FS may have a direct effect on FEI in addition to any effects mediated by mental health. A mental distress latent variable was derived from the anxiety and depression scales. Parameter estimates and fit statistics of the proposed model are provided in **Table 3**.

In line with the proposed model, significant direct effects of mental distress and FS on FEI were observed. As mental distress and FS increased, FEI increased. There were also significant direct effects of FS, FT and SS on mental distress. As expected, mental distress was increased by FT and FS, but reduced by SS. The indirect effects of FS, FT, and SS on FEI were not significant, but were in the expected direction. SS negatively correlated with FS and FT, suggesting potential benefits of SS in reducing these sources of mental distress.

The proposed model was compared to alternative models to assess whether it provided the most appropriate model of the obtained data. First, the latent variable of mental distress was removed and anxiety replaced it as the mediator of first-order effects on FEI. The resulting model (anxiety mediation)

TABLE 3 | Parameter estimates of the original structural equation model.

	b	SE	*β*	95% CI	*p*
Direct effects					
On FEI					
Mental distress	0.234	0.119	0.245	(0.00, 0.47)	0.050
Farm stress	0.010	0.004	0.267	(0.00, 0.02)	0.018
On Mental distress					
Farm stress	0.013	0.004	0.332	(0.01, 0.02)	0.001
Social support	–0.016	0.006	–0.237	(–0.03, 0.00)	0.009
Financial threat (log)	0.698	0.173	0.379	(0.36, 1.04)	<0.001
Latent variable					
Mental distress					
Anxiety (log)	1.000		0.856		–
Depression (log)	0.891	0.121	0.785	(0.65, 1.13)	<0.001
Indirect effects					
Farm stress > Mental distress > FEI	0.003	0.002	0.081	(0.00, 0.01)	0.089
Social support > Mental distress > FEI	–0.004	0.002	–0.058	(–0.01, 0.00)	0.110
Financial threat (log) > Mental distress > FEI	0.163	0.090	0.093	(–0.01, 0.34)	0.071

CFI stands for comparative fit index, TLI stands for Tucker–Lewis index. RMSEA stands for root mean square error of approximation. Values obtained from lavaan (version.5-20) R package (66, 67).

Note: $\chi^2(5) = 3.687$, p = 0.595; CFI = 1.0; TLI = 1.024; RMSEA = 0.000 (90% CI = 0.00–0.12).

demonstrated good fit with a non-significant chi-square test (3.106, $p = 0.212$), IFI value of.984 and a CFI value of.985. This model had an AIC value of 2555.57, which was marginally better than the AIC value of the proposed latent variable model (2628.17), but not significantly so [$\chi^2(3) = 0.58171$, $p = 0.9006$], suggesting the simpler model was the more parsimonious alternative. However, the fit statistics for the simpler model were not as good as the proposed model. The chi-square (3.687, $p = 0.595$), CFI (1.0), and IFI (1.01) values were all superior for the original proposed model. The RMSEA was lower for the proposed model (0.000) than the simpler model (0.072) and the 90% confidence interval was tighter (proposed model: 0.00–0.12, simpler model: 0.00–0.22).

Farm stress is a heterogeneous construct and the EFSS includes FT and isolation as components of the FS measure (see **Figure 1**). To assess whether some of the effect of FT or SS might have been mitigated by these subscales of the FS measure, we estimated the correlation between the Financial and Isolation subscales of the FS measure and the log-transformed FT score and the SS measure. The obtained correlation between the financial measures was $r = 0.642$, $p < 0.0001$, a strong correlation and the correlation between isolation and SS was $r = -0.250$, $p = 0.006$, a weak to moderate correlation. Given the strength of the correlation between the financial measures, we developed a non-financial FS score by excluding scores from the Financial subscale of the FS measure. We then included this non-financial FS as a first-order predictor in place of the original FS measure. Results of this analysis are presented in **Table 4**.

Most of the effects in the revised model were the same as those observed in the proposed model. There were a number of differences however. The non-financial FS measure was not a significant direct predictor FEI, but mental distress was. In addition, the indirect effects of non-financial FS and FT were both significant in the revised model. Nevertheless, even though the significance of some effects was affected in the new model, the patterns of correlation were largely similar. Since the revised model more clearly estimated the effects of FT, it was preferred to the original proposed model (see **Figure 2**).

To test the deleted paths in the revised model, paths from SS and FT to FEI were added to the proposed model (full model). This model had an AIC value of 2243.1, which was marginally worse than the AIC value of the proposed model (2242.6) but not significantly so [$\chi^2(2) = 3.5045$, $p = 0.1734$]. The direct paths from SS and FT to FEI were not significant in the full model, suggesting that their deletion from the proposed model was appropriate. Two trimmed models were compared to the proposed model. In the first reduced model (reduced model 1), the direct path from FS to FEI was removed. The second reduced model had an AIC value of 2243.8, which almost identical, but slightly worse than the AIC value of the proposed model [$\chi^2(1) = 3.2439$, $p = 0.07$]. All of the fit statistics (e.g., RMSEA, CFI) for this reduced model were worse than the revised model. In the second reduced model (reduced model 2), the direct path

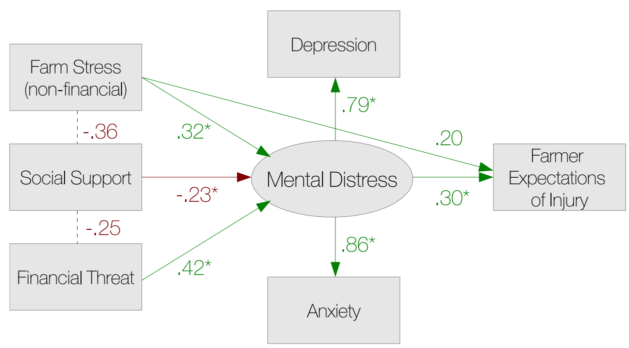

FIGURE 2 | Path diagram of the model of farmers' expectations of injury supported by the current analyses. Asterisks denote relationships that are significant at $p < 0.05$.

TABLE 4 | Parameter estimates of the revised structural equation model that replaced the original farm stress measure with the non-financial farm stress measure.

	b	SE	β	95% CI	p
Direct effects					
On FEI					
Mental distress	0.283	0.118	0.295	(0.05, 0.51)	0.016
Farm stress (non-financial)	0.009	0.005	0.202	(0.00, 0.02)	0.067
On Mental distress					
Farm stress (non-financial)	0.015	0.004	0.323	(0.01, 0.02)	0.001
Social support	−0.015	0.006	−0.226	(−0.03, 0.00)	0.014
Financial threat (log)	0.776	0.168	0.423	(0.45, 1.10)	<0.001
Latent variable					
Mental distress					
Anxiety (log)	1.000		0.852		–
Depression (log)	0.898	0.121	0.787	(0.66, 1.13)	<0.001
Indirect effects					
Farm stress > Mental distress > FEI	0.004	0.002	0.095	(0.00, 0.01)	0.048
Social support > Mental distress > FEI	−0.004	0.002	−0.067	(−0.01, 0.00)	0.078
Financial threat (log) > Mental distress > FEI	0.219	0.099	0.125	(0.03, 0.41)	0.027

CFI stands for comparative fit index, TLI stands for Tucker–Lewis index. RMSEA stands for root mean square error of approximation.
Note: $\chi^2(5) = 4.257$, $p = 0.513$; CFI = 1.0; TLI = 1.014; RMSEA = 0.000 [90% CI = 0.00–0.13].

from mental distress to FEI was removed. The second reduced model had an AIC value of 2244.5, which was also very similar, but slightly worse than the AIC value of the proposed model [$\chi^2(0) = 1.9223$, $p = 0.02135$]. Once again, all of the fit statistics (e.g., RMSEA, CFI) for this reduced model were inferior to those of the revised model.

DISCUSSION

The current study investigated relationships between FT, SS, farm job stress, mental distress, and FEI. The findings support the conclusion that mental distress mediates the effects of non-financial FS and FT FEI. Indirect influences of SS on FEI were in the expected direction but non-significant. That is, non-financial FS and FT contribute to mental distress and mental distress affects FEI. Non-financial FS and FT significantly increased mental distress and SS significantly reduced mental distress. Significant indirect relationships were found between FEI and FT and farm job stress. Non-financial FS did not significantly predict FEI directly, but the path improved the fit of the model, suggesting that stress may have direct effects on FEI. This suggests that some of the effects of stress are not mediated by mental distress.

One interpretation of the patterns of relationships observed in the current study is that general FS and financial worries reduce the farmer's available resources to deal with the farm and that SS supplements those resources. Such an interpretation is in line with the Conservation of Resources theory described earlier. Interventions for farmers would, thus, be best directed at reducing known stressors and financial uncertainty for farmers and ensuring that farmers are receiving SS. The trend toward mechanization and infrastructural investment in farming means that farmers spend more time lone working, which increases stress and reduces SS. In addition, the transmission of safety best practices through the farming population is likely best facilitated through peer networks of farmers speaking to farmer (53). Consequently, initiatives that seek to connect farmers can have multiple benefits for farm safety and productivity.

Previous research has indicated that farmers suffering from mental distress are less likely to engage with health and safety leading to injury (54). The current findings suggest that farmers are, to some degree, aware of the compromises that they feel they need to make for the farm to survive. The CoR approach suggests that it is possible for farmers to become embroiled in a negative spiral in which dysfunctional coping strategies, such as "cutting corners," lead to accidents that further reduce the farmer's ability to run the farm. Given that farmers are required to make substantial financial investments to run their farms, such negative spirals, can result in farmers losing their farms and their livelihoods.

Improving the health and safety of farmers is necessary for the viability of the profession, has implications for national food security, and, in Ireland, is essential to the export economy. Consequently, there is an obligation on policy makers to facilitate enhancements in this area (55). Farmers contact a range of stresses and, in many cases, current business models often expose them to high levels of financial risk. Traditional sources of SS have also been somewhat eroded in recent years. How best to develop policy interventions to support farmers has been an important goal of the field of agricultural extension. An important concept in this literature is the agricultural knowledge and information system (AKIS), in which farmer is centrally positioned with access to multiple sources of knowledge and information from research, extension, and education (56). The AKIS approach may provide a framework through which to develop interventions to enhance farmer health and safety. With a particular focus on mental health, greater collaboration between farmer representative groups, development groups, and government departments of health and agriculture will facilitate more appropriate intervention. Farmers would also benefit from interventions, such as mental health first aid (57, 58), that normalize healthy coping strategies (59) and minimize exposure to mental health stigma.

The current data provide an interesting snapshot of the Irish dairy farmer in 2015. The majority of farmers did not feel susceptible to injury, but the average for the sample was significantly higher than that found by Hodne et al. (43). There are a number of differences between the samples. First, the farmers in the current sample were exclusively dairy farmers, whereas the sample recruited by Hodne et al. was mixed (33% produced cattle, 41% hogs). In Ireland, dairy farming contributes a higher proportion of fatalities than other types of farming, so this may explain the difference in expectations of injury. The average FT experienced by the sample was lower than that recorded by Marjanovic et al. (45), suggesting that the sample felt relatively financially secure. Consequently, in the analyses we conducted, this variable was log transformed to correct for skew and to enhance the sensitivity of the scale at the low end. In addition, the vast majority of the sample had either recently expanded or were about to expand in the coming years, so there might have been a selection effect that prioritized farmers who were on a better financial footing. However, the stress levels observed in the population were very similar to those reported by Deary et al. (9). Nevertheless, such selection effects would likely have reduced the obtained correlations and the strength of associations found among the variables. Part of the challenge of measuring the effects of stress on farmers is that those farmers who are most stressed are least likely to be willing to spend time completing surveys. Though we had considerable buy-in from the farming community, it is still difficult to access those most in need of financial and statement concerns both financial support and social support.

We employed two measures of mental distress that are designed to identify clinical levels of anxiety and depression. Both these scales have previously been employed with population samples (48, 52) and, given the stress that farmers contact at work, we expected to observe greater levels of mental distress in the sample that were obtained. There are three possible reasons for this effect. First, the aforementioned selection effect might have meant that we included dairy farmers who were less stressed and more financially secure. Such farmers were more likely to come into contact with the researchers and more likely to complete surveys. Second, farmers might be more resilient (60) to stress and financial worry than the general population. Finally, it is possible that farmers may be unwilling to acknowledge symptoms of poor mental health due to a "macho" (59) perception that such symptoms constitute evidence of weakness. It is not possible to adjudicate between these possibilities with the data available to us. As with FT, if a greater spread of mental distress was obtained, it would provide clearer relationships with injury expectations. As with FT, log transformations were employed that corrected for skew and increased the sensitivity of the scales at low end. For future research, however, we would recommend employing a scale that may be more sensitive to lower levels of depression in the general population, such as the Centre for Epidemiologic Studies Depression scale [CES-D; (61)], as an alternative.

The impact of FT on farmers' mental wellbeing constitutes a microcosm of the effects of FT on mental health in the rest of the population. The recent recession had considerable effects on population mental health through greater FT, especially through unemployment (62, 63). For many of us, we feel a moral imperative that financial conditions that are largely beyond an individual's control should not cause excessive suffering. However, the case for protecting citizens from FT is not just moral, it is also economic. When individuals suffer mental distress, they are less productive at work and may need to abstain from work resulting lost productivity. Treating mental health problems is also very costly. In the USA in 2000, the costs (indirect and direct) of depression alone have been estimated at $76 billion (64, 65). It is clear that, in the case of FT, prevention of mental health problems is better than cure from both an economic and social justice perspective.

AUTHOR CONTRIBUTIONS

DO, EF, and JM designed the research study. EF and JM conducted the research. EF, DO, and JM wrote the paper and all authors proposed revisions. CN provided statistical analysis expertise.

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Online Design Aid for Evaluating Manure Pit Ventilation Systems to Reduce Entry Risk

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On-farm manure storage pits contain both toxic and asphyxiating gases such as hydrogen sulfide, carbon dioxide, methane, and ammonia. Farmers and service personnel occasionally need to enter these pits to conduct repair and maintenance tasks. One intervention to reduce the toxic and asphyxiating gas exposure risk to farm workers when entering manure pits is manure pit ventilation. This article describes an online computational fluid dynamics-based design aid for evaluating the effectiveness of manure pit ventilation systems to reduce the concentrations of toxic and asphyxiating gases in the manure pits. This design aid, developed by a team of agricultural engineering and agricultural safety specialists at Pennsylvania State University, represents the culmination of more than a decade of research and technology development effort. The article includes a summary of the research efforts leading to the online design aid development and describes protocols for using the online design aid, including procedures for data input and for accessing design aid results. Design aid results include gas concentration decay and oxygen replenishment curves inside the manure pit and inside the barns above the manure pits, as well as animated motion pictures of individual gas concentration decay and oxygen replenishment in selected horizontal and vertical cut plots in the manure pits and barns. These results allow the user to assess (1) how long one needs to ventilate the pits to remove toxic and asphyxiating gases from the pit and barn, (2) from which portions of the barn and pit these gases are most and least readily evacuated, and (3) whether or not animals and personnel need to be removed from portions of the barn above the manure pit being ventilated.

Keywords: computer simulation, contaminant gas evacuation, manure pit ventilation, agricultural safety, oxygen replenishment

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INTRODUCTION

On-farm manure storage pits contain both toxic and asphyxiating gases. The primary gases of concern are hydrogen sulfide, ammonia, carbon dioxide, and methane. Occasionally, farm workers must enter the manure storage pits for maintenance and repair. Most farms do not have self-contained breathing devices; many do not have toxic and asphyxiating gas detection devices. Consequently, farm workers often enter the manure pits unprotected, lose consciousness, and die. Tragically, such incidents often result in multiple deaths as an observing worker tries to assist the one originally overcome by the toxic and asphyxiating gases. Beaver and Field (1) summarized documented fatalities in livestock manure storage and handling facilities from 1975 to 2004. One result from this analysis of 77 fatalities cases showed an increasing trend in the death rate: 1.6 per year from 1975 through 1984, 2.7 per year from 1985 through 1994, and 3.5 per year from 1995 through 2004.

One intervention to reduce the toxic and asphyxiating gas exposure risk to farm workers entering the manure pits is manure pit ventilation. The basic questions then become: (1) how much and for how long must the manure pit be ventilated to reduce entry risk? and (2) does the manure pit ventilation contaminate portions of the barn above manure pits during pit ventilation? This article describes a user-friendly, online computational fluid dynamics (CFD)-based design aid for evaluating the effectiveness of manure pit ventilation systems to reduce the concentrations of toxic and asphyxiating gases in manure pits. To the best of our knowledge, this is the first online CFD-based manure pit ventilation system design aid and analysis tool available to agricultural waste facilities planners, agricultural building design professionals, industrial hygienists, regulatory agencies, and emergency responders. The online design aid is organized into four modules, one each for solid-covered stand-alone manure pits (**Figure 1**), slotted-covered manure pits beneath tunnel-ventilated barns (**Figure 2**), slotted-covered manure pits beneath cross-ventilated barns (**Figure 3**), and slotted-covered manure pits beneath naturally ventilated barns (**Figure 4**).

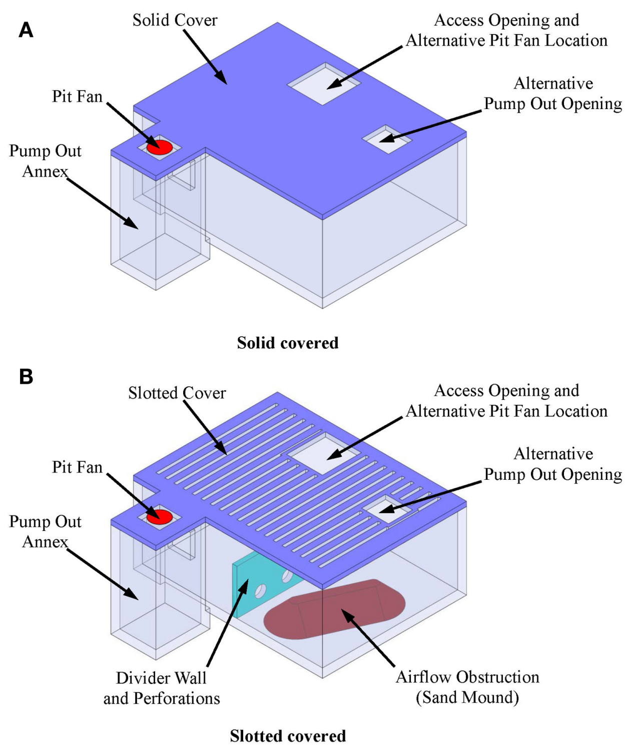

FIGURE 1 | Definition sketch of stand-alone manure pits with (A) solid cover and (B) slotted cover illustrating online tool additional features.

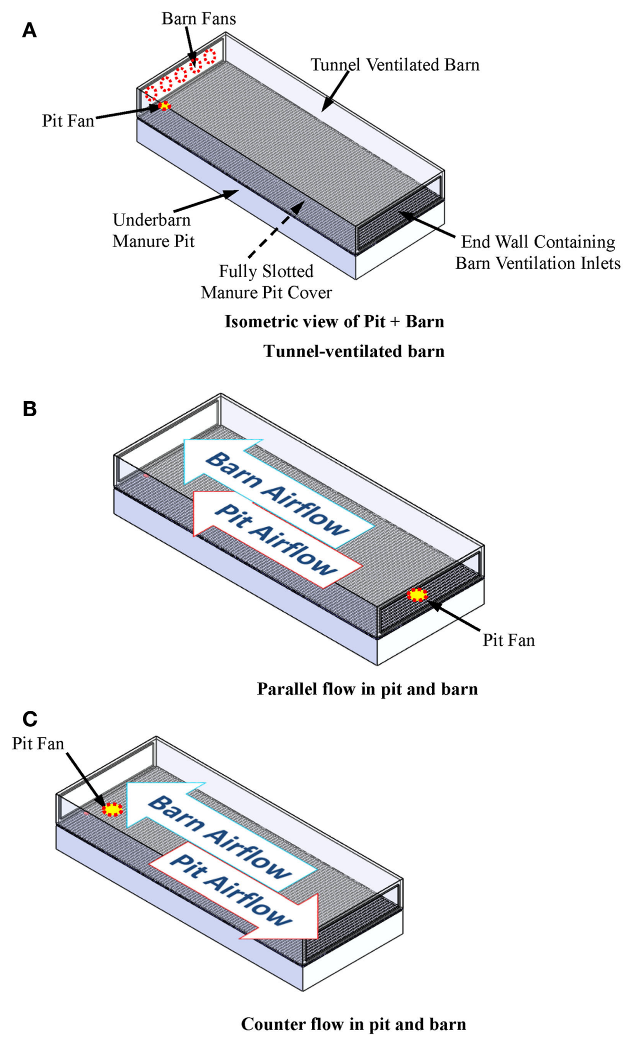

FIGURE 2 | (A) Definition sketch of a slotted-covered manure pit beneath a tunnel-ventilated barn; **(B)** parallel flow in tunnel-ventilated pit + barn; and **(C)** counter flow in tunnel-ventilated pit + barn.

The design aid is intended to be used primarily by waste management specialists, animal facilities designers, engineers, agricultural safety specialists, emergency rescue, and regulatory personnel who wish to assess the effectiveness of existing or alternative manure pit ventilation systems to remove contaminant gases and replenish oxygen prior to personnel entry. Typical applications of the design aid include (1) screening alternative ventilation system layouts to determine which is most effective for removing contaminant gases; (2) estimating required manure pit ventilation times to evacuate contaminant gases for a given ventilation system layout to concentrations suitable for human long-term occupancy (2, 3); (3) estimating required manure pit ventilation times to replenish oxygen levels to 20% by volume (3); and (4) determining which areas of barns above slotted-covered manure pits become contaminated to levels requiring evacuation of animals and personnel prior to and during manure pit ventilation.

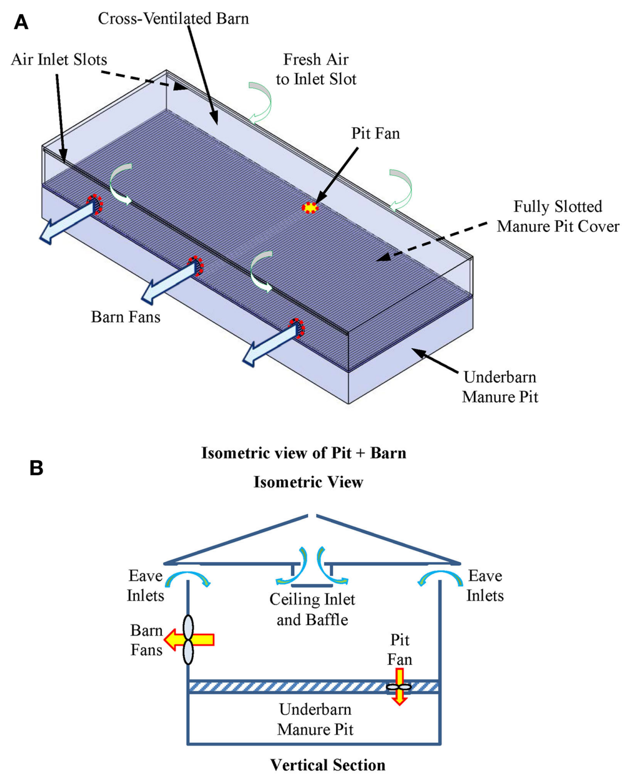

FIGURE 3 | Definition sketch of a slotted-covered manure pit beneath a cross-ventilated barn. **(A)** Isometric view and **(B)** vertical section showing general airflow direction in barn.

EQUIPMENT REQUIREMENTS

The design aid resides on a Pennsylvania State University server. It consists of (1) a pre-processing package in which user input, such as basic building and ventilation system data, is transformed into a format suitable for the CFD simulation program; (2) the CFD software package SolidWorksFlowSimulation® (SWFS®); (3) a preview module that allows a user to view a 3-D visualization of the input data; and (4) a post-processing module that retrieves and transforms the SWFS® results into a user-friendly format. User minimum computer software requirements for inputting, accessing, and interpreting design aid results are (1) the latest version of Internet Explorer, Firefox, or Chrome; (2) Microsoft Excel® 2010; and (3) the latest version of Adobe Reader.

BACKGROUND AND SUPPORTING RESEARCH

The supporting published research for development of the design aid was conducted and reported by a Pennsylvania State University research team in a series of five journal articles (4–8). These journal articles served as the basis for development and publication of a peer reviewed and American National Standards Institute (ANSI) approved engineering standard, ANSI/ASABE Standard S607, on ventilation of confined-space manure storages to reduce entry risk (9, 10). This is the first engineering standard to address specific ventilation strategies, including fan location, outlet location, air exchange (AC) rates, and ventilation times required to reduce contaminant gases in confined-space manure storages to below either Occupational Safety and Health Administration (OSHA)-defined personal exposure levels (PELs) or American Conference of Governmental Industrial Hygienists (ACGIH)-defined threshold limit values (TLVs) for hydrogen sulfide, carbon dioxide, and methane, and to replenish oxygen levels from 0% to ACGIH-defined TLVs for oxygen.

Occupational Safety and Health Administration has developed confined-space regulations documented in the 29 Code of Federal Regulations (CFR) Part 1910.146 (11). Manure storages are confined spaces, but Agriculture was exempted from OSHA's 1910.146 standard when it first passed in 1993. Even so, the authors have used standard 1910.146 as a reference point for the atmospheric hazards associated with confined-space manure storages. These regulations require that the internal atmosphere within a confined space be tested for oxygen levels, flammable gases and vapors, and potential noxious contaminants prior to human entry. According to OSHA standards, an employee may not enter a confined space until forced-air ventilation has eliminated any existing hazardous atmosphere. Thus, it is imperative that confined spaces be properly ventilated prior to entry. The OSHA-defined PEL for hydrogen sulfide is 10 ppm; the ACGIH-defined TLV for hydrogen sulfide is 1 ppm (2, 3). The ACGIH-defined TLVs for methane and ammonia are 1,000 and 25 ppm, respectively (3). The OSHA-defined PEL for carbon dioxide is 5,000 ppm (2). The ACGIH-defined TLV for O_2 in confined spaces prior to entry is 19.5% by volume up to an altitude of 1,525 m (3).

In experimental studies, hydrogen sulfide (H_2S) was used as an indicator gas to investigate the effectiveness of forced-ventilation strategies for eliminating the toxic and oxygen-deficient atmospheres in the confined-space manure pits. Typical H_2S concentration reduction curves during forced-air ventilation were identified in a rectangular manure tank. Based on the experimental tests conducted in the research, the most promising candidate ventilation strategies were identified for the studied rectangular confined-space manure tank with solid, totally slotted, and partially slotted covers. In addition, based on results of experimental tests, a field-based database was developed for the validation of CFD modeling protocols (4). As an important input parameter of the CFD modeling protocols, manure gas emissions were measured experimentally using the same rectangular tank. The influencing factors on gas emissions were identified as well (5).

The CFD modeling protocols to simulate H_2S removal from fan-ventilated confined-space manure storages were developed and validated. The CFD model was used to conduct the simulations of evacuating H_2S during forced ventilation for the best ventilation strategies identified in the work by Pesce et al. (4) for a typical rectangular on-farm manure tank with three cover types (i.e., solid, totally slotted, and partially slotted). Validation of the CFD modeling protocols was based on comparisons between simulated and measured H_2S evacuation times. Simulated and measured evacuation times within

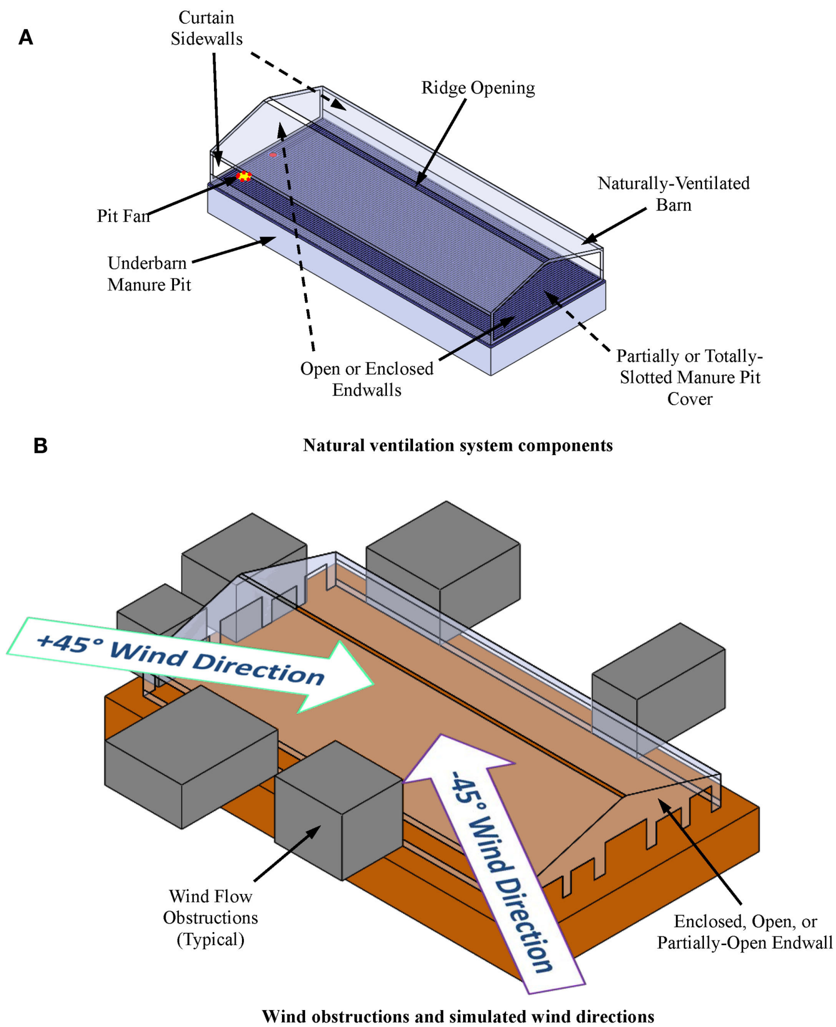

FIGURE 4 | Definition sketches for naturally ventilated barn above slotted-covered manure pit. **(A)** Natural ventilation system components and **(B)** wind obstructions and wind directions simulated by online design aid.

the confined-space manure storage facilities evaluated agreed within 10% at all measuring locations except those immediately adjacent to the ventilation fan jet for all three cover types for both high (5 AC min^{-1}) and low (3 AC min^{-1}) AC rates. Corresponding evacuation times agreed to within 15% for all cover types and AC rates in the high-velocity gradient region of the ventilation fan jet. Having agreement to within 15% in these high-velocity gradient zones was justified because contaminant gas concentrations in these regions were evacuated rapidly to very low levels, and small differences in measuring locations would produce additional percentage differences in results. These results demonstrated that the CFD modeling protocols developed satisfactorily predict the gas concentration decay during forced ventilation in confined-space manure pits (6). The validated CFD modeling protocols were then applied to conduct simulations for identifying manure gas evacuation times and oxygen level recovery in the confined-space manure pits with different footprints. The factors (i.e., AC rate, manure gas emission rates, and gas initial concentration) influencing the gas evacuation time were identified (7, 8).

Design engineers and agricultural building planners often use one of the several computer-aided design (CAD) software packages, such as SWFS® (12–14), for many design applications, especially for more complex tasks. Assessing the performance of ventilation systems for confined-space manure storages is a fairly complex engineering task for which a CAD software package with CFD capability is very useful. The SWFS® software package includes a user-friendly CFD application suitable for simulating and designing ventilation systems for evacuating contaminant gases from and replenishing oxygen in confined-space manure storages. The SWFS® software package was used in conjunction with the CFD simulation protocols developed by the Pennsylvania State University research team to develop the online design aid.

The suitability of the SWFS® CFD software for the online tool development was verified by comparing SWFS® simulated H_2S

gas decay vs. ventilation responses to those measured by Pesce et al. (4) and simulated using Phoenics as reported by Zhao et al. (5). These comparisons were made for H_2S gas decay in a 2.74-m wide by 5.49-m long by 1.83-m deep solid covered manure tank at two ventilation rates (high – 5 AC/m and low – 1.0 AC/m). The best agreement between the Phoenics simulated and measured results were obtained with a CFD simulation time step size of 10 s. The Phoenics simulation results were validated by successfully matching the simulated and measured H_2S decay vs. ventilation time response at 10 locations within the tank (5 upper level locations and 5 lower locations). Upper level location R^2 values for simulated vs. measured decay curves were 0.94 and 0.85, respectively, for the high and low AC rates. Corresponding R^2 values for the lower level grid locations were 0.88 and 0.93. The SWFS® simulated H_2S decay curves also were in excellent agreement with the measured decay data for the manure pit described by Pesce et al. (4). For the high AC rate, a 5-s time step provided the best match with the measured data for the upper grid ($R^2 = 0.94$). A 7-s time step provided the best match with the measured data for the lower grid ($R^2 = 0.85$). For the low AC rate, a 5-s time step provided the best match for both the upper ($R^2 = 0.81$) and lower ($R^2 = 0.88$) grid locations.

STEPWISE PROCEDURES

Underlying Assumptions and Justifications

The primary assumptions for development of the online tool are (1) the manure pit is ventilated with a positive pressure ventilation system; (2) there are no ventilation air distribution ducts inside the manure pit; (3) the barn above a slotted-covered manure pit is negative pressure ventilated at the design hot weather ventilation rate for a fully stocked animal facility prior to and during pit ventilation; (4) the manure pit is nearly empty (i.e., only residual manure of approximately 150 mm or less remains inside the pit); (5) the contaminant gas concentrations are initially uniformly throughout the manure pit domain; (6) initial oxygen levels inside the manure pit are 0% by volume; and (7) the barn atmosphere is free of contaminant gases, and the oxygen content is 20.9% by volume prior to manure pit ventilation.

Positive pressure pit ventilation is assumed because many manure pit configurations, especially those with slotted covers, are prone to short circuiting of ventilation air flow patterns. Positive pressure ventilation systems are less prone to short circuiting than are negative pressure ventilation systems. Ventilation air distribution ducts large enough to provide the manure pit AC capacity required for removal of contaminant gases to levels suitable for pit entry in a reasonable ventilation time frame are not practical. They significantly reduce manure pit capacity and are expensive to install. In addition, in existing facilities, installing a satisfactory temporary air distribution duct is not a reasonable option. Since installation of such distribution ducts is an essential component of satisfactory ventilation of short circuiting prone manure pits ventilated with negative pressure systems, the first underlying assumption is further justified. The third assumption is imposed to minimize the cross-contamination of the barn space above slotted-covered manure pits during positive pressure ventilation of the pit. Any properly designed ventilation system in the barn above a manure pit will have a ventilation system capacity able to achieve the design hot weather ventilation rate defined in ASABE EP270.5 (9) and MWPS (15) for a fully stocked animal facility. Assumption four is imposed for practical safety considerations. Assumption five is justified and conservative if initial gas concentration levels are measured at several locations inside the manure pit prior to pit ventilation and the maximum measured concentration used for the initial condition. Assumption six assures a conservative initial condition and required pit ventilation time before entry. Assumption seven is obtained by ventilating the barn above slotted-covered manure pits at the hot weather rate for approximately 2–5 min prior to manure pit ventilation.

Other design aid module-specific assumptions are imposed. These are identified in the more detailed presentations of the individual design aid modules.

Accessing the Design Aid

The design aid is accessed at the website: https://ventdesign.agsafety.psu.edu. Users follow the prompts to register to use the online design tool and are notified by email that they can submit projects.

Input Data Entry

The user is prompted to complete a general information form. This includes some demographic information about the user and the animal enterprise for the current project submission. Then, the user is prompted to enter project-specific data necessary to characterize the manure pit and barn geometry, the pit ventilation system, and the barn ventilation system. Data entry for the online design aid is in English units. This unit system was selected because English units are the preferred platform for the vast majority of anticipated design aid users. Only two soft conversions are required to convert all required inputs from SI to English units: (1) the size and location of geometric features from meters to feet and inches and (2) fan airflow capacity from cubic meters per second to cubic feet per minute.

Selection of the Simulation Module

The user selects the simulation module that best describes the project manure pit and barn. The four simulation modules are (1) stand-alone manure pits (**Figure 1**), (2) tunnel-ventilated barns above slotted floor covered manure pits (**Figure 2**), (3) cross-ventilated barns above slotted floor covered manure pits (**Figure 3**), and (4) naturally ventilated barns above slotted floor covered manure pits (**Figure 4**). Upon simulation module selection, the user is directly transferred to the specific data input pages for the project. Input protocols for stand-alone manure pits are first presented followed by protocols for barns above slotted-covered manure pits. Many input protocols are common across all modules; however, some are unique to a given simulation module.

Inputs for Stand-alone Manure Pits

When in the stand-alone manure pit module, the user is prompted with dialog boxes to enter in turn (**Figure 1**):

- Pit fan capacity.
- Initial concentration of hydrogen sulfide, carbon dioxide, methane, and ammonia in the manure pit in parts per million (default values of 120 ppm H_2S, 700 ppm CO_2, 15,000 ppm CH_4, and 240 ppm NH_3 are in the program but can be changed by the user).
- Manure pit cover thickness.
- Manure pit length, width, and height.
- Manure pit ventilation inlet diameter and location defined by *X*- and *Y*-offset distances from the defined Cartesian coordinate system origin (**Figure 5A**).
- Offset angles for the manure pit ventilation inlet in degrees (if *X*- and *Y*-offsets for the inlet location are positive, both the *X*- and *Y*-offset angle is 90°; if *X*-offset distance is negative, the *X*-offset angle is 270°; and if *Y*-offset is negative, then *Y*-offset angle is 270°).

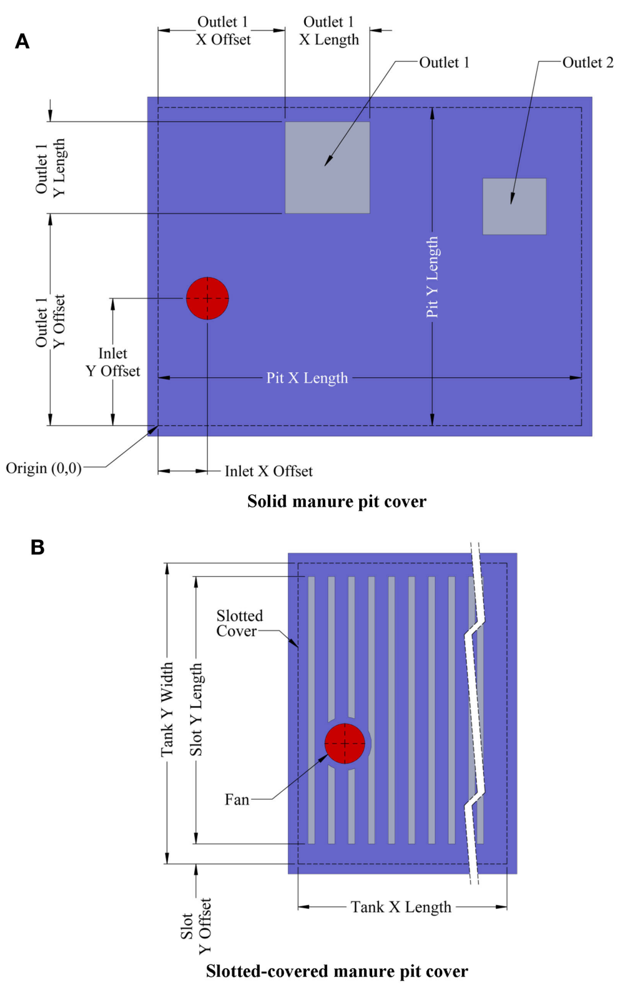

FIGURE 5 | **Definition sketches for inputs for (A) solid manure pit covers and (B) slotted-covered manure pit covers.**

- Manure pit cover details including whether cover is solid or slotted. A solid cover is the default mode in all modules. For slotted covers, the slotted cover option is selected. Then, the user can define the slotted cover domain (partial or totally slotted) by indicating the *X*- and *Y*-offset distances to the beginning of each slotted cover area, the length and width of each slotted floor domain, the width of slats in each domain, and the width of the slots between slats in each slotted cover domain (**Figure 5B**).
- Dimensions and *X*- and *Y*-offset distances of up to two manure pit ventilation air outlets for solid covered manure pits. The slots of the covers serve as the manure pit ventilation outlets for slotted-covered manure pits (**Figure 5A**).
- Location, defined again by *X*- and *Y*-offset distances, and lengths of any longitudinal or transverse divider walls in the manure pit (**Figure 1B**).
- Location and size (width and height) of up to three perforations in each manure pit divider wall (**Figure 1B**).
- Locations (*X*- and *Y*-offsets) and dimensions (length, width, and height) of any obstructions to airflow inside the manure pit. A sand mound resulting from the use of sand for bedding is and example of such an obstruction to airflow in the manure pit (**Figure 1B**).
- Location (*X*- and *Y*-offset distances and *X*- and *Y*-offset angles) and dimensions (length, width, and height) of any manure pit pump-out annexes (**Figure 6A**). Annex inputs also specify the size and location of the pit wall opening to the annex and the option to place the manure pit fan in a pump-out annex (**Figure 6B**).
- Source of manure pit ventilation air. The source can be either (1) recirculated air from directly above the manure pit cover or (2) fresh non-contaminated atmospheric air ducted from a location removed from the manure pit cover.
- Direction of manure pit fan airflow into the pit. The air flow can be directed vertically downward into the pit or it can be directed at any vertical angle from horizontal or at any horizontal angle measured from the manure pit longitudinal axis (**Figures 7A,B**).

Checks, Balances, and Job Submission

At any point during the input process, the user can check the input for errors by clicking onto the "Check Constraints" or the "Preview" buttons. The "Check Constraints" button activates a set of equations that checks if geometric entities fall outside of prescribed domains. For example, if a solid-covered pit ventilation outlet falls outside the geometrical domain of the manure pit, the Check Equations identifies this error and sends back an error message. Checking the "Preview" button generates a 3-D rotatable sketch of the manure pit, complete with pit ventilation fan and outlet locations, pump-out annex locations, and other geometric features. This feature helps the user quickly identify geometric and ventilation system input errors. Once the checks have been conducted and any required corrections made, the user clicks the "Save Study" button. This sends the input file to the host server, where it is converted into a format compatible with SWFS® and the simulation is run. The user is informed by email when the simulation is completed and the results are available. At this time,

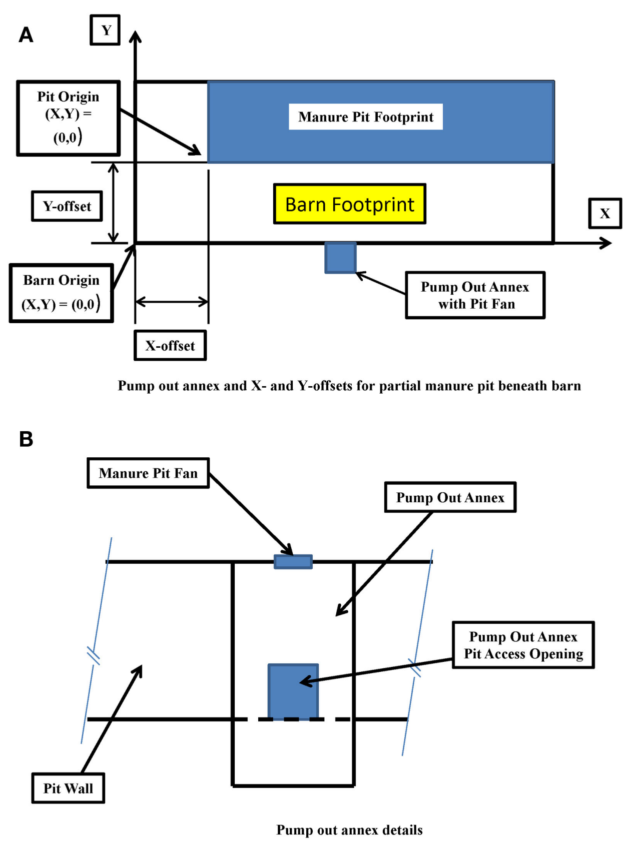

FIGURE 6 | **Definition sketches for (A) typical manure pit pump-out annex and manure pit offsets and (B) pump-out annex details.**

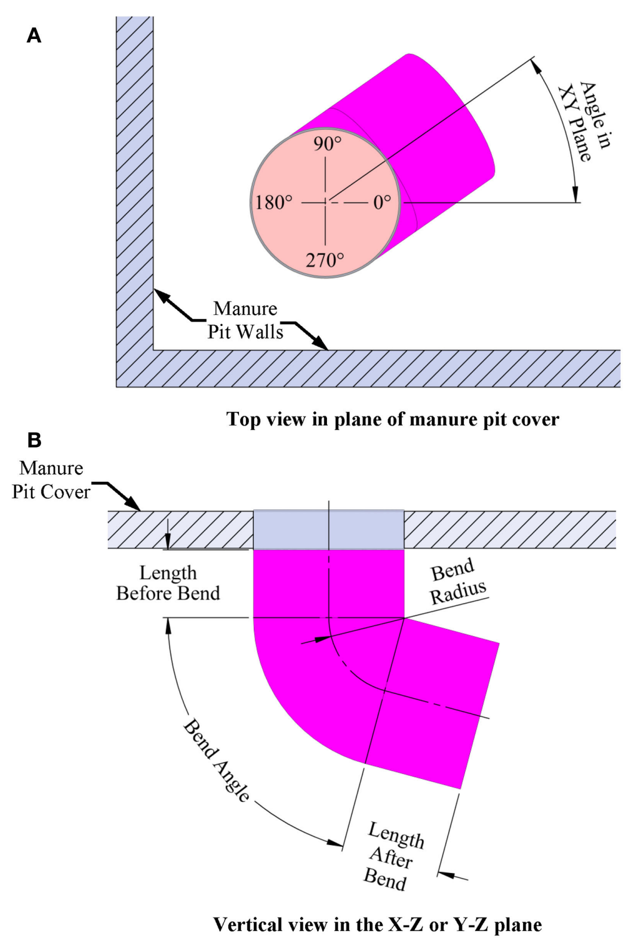

FIGURE 7 | **Definition sketch for pit fan air direction controller: (A) Top view and (B) Side view.**

the user again accesses the online tool and follows the prompts to access the simulation results.

Inputs for Slotted-Covered Manure Pits beneath Tunnel-Ventilated Barns

After accessing the design aid as explained in Section "Accessing the Design Aid," the user first selects the tunnel-ventilated option (**Figure 2**). Three input navigation buttons (Pit Geometry, Barn Geometry, and Pit + Barn) appear at the top of the next input page. The Pit Geometry button directs the user to the data entry for characterizing the pit geometry and pit ventilation details. All data inputs for slotted-covered manure pits beneath naturally ventilated barns are identical to those listed in Section "Inputs for Stand-Alone Manure Pits" for stand-alone manure pits except those for the manure pit ventilation outlets. The slotted floor openings serve as the manure pit ventilation outlets for slotted-covered pits with barns above them.

To enter data for the barn above the manure pit, the user selects the Barn Geometry navigation button. The user is then prompted with dialog boxes to enter the following barn information in turn:

- Barn total fan capacity;
- Barn length (X-direction), width (Y-direction), and ceiling height (Z-direction);
- Barn ventilation air inlet dimensions in the end wall opposite the ventilation fan locations. The barn fan location is always located in the end wall at which $X = 0$.

To establish where the manure pit is located relative to the barn (i.e., define whether the manure pit extends partially or totally under the barn), the user selects the Pit + Barn navigation button. The user then inputs the X- and Y-offsets for the manure pit relative to the barn (**Figure 6A**).

The same checks and balances described in Section "Checks, Balances, and Job Submission" are available at any stage of data input for the manure pit beneath tunnel-ventilated barn cases. These checks and balances are available when in any of the three input phases (Pit Geometry, Barn Geometry, or Pit + Barn). Once satisfied with the accuracy of the input data, the user saves the input file and submits it for CFD simulation of the manure pit ventilation and contaminant gas evacuation.

Inputs for Slotted-Covered Manure Pits beneath Cross-Ventilated Barns

After accessing the design aid as explained in Section "Accessing the Design Aid," the user first selects the cross-ventilated option

(**Figure 3**). With the three previously described (see Inputs for Slotted-Covered Manure Pits beneath Tunnel-Ventilated Barns) input navigation buttons (Pit Geometry, Barn Geometry, and Pit + Barn), the user inputs in turn the required manure pit, barn, and barn + pit geometrical and ventilation system data. All data inputs for slotted-covered manure pits beneath cross-ventilated barns are identical to those listed in Section "Inputs for Stand-Alone Manure Pits" for stand-alone manure pits except those for the manure pit ventilation outlets. The slotted floor openings serve as the manure pit ventilation outlets for slotted-covered pits with barns above them.

To enter data for the cross-ventilated barn above the manure pit, the user selects the Barn Geometry navigation button. The user is then prompted with dialog boxes to enter the following barn information in turn:

- Barn length (X-direction), width (Y-direction), and eave height (Z-direction);
- Select the sidewalls or end walls in which barn fans are located;
- Total fan capacity of all fans in each sidewall or end wall;
- Number of fans in each sidewall or end wall;
- Diameter of fans in each sidewall or end wall;
- X- or Y-offset distance for first fan in each sidewall or end wall (**Figure 3A**);
- Z-offset distance for all fans in each sidewall or end wall;
- Spacing of multiple fans in each sidewall or end wall;
- Length and width of eave ventilation air inlets in each sidewall and end wall;
- Eave inlet blocking locations in each sidewall or end wall;
- Location and dimensions of any barn inlet ducts or drop inlets located between the barn sidewalls (**Figure 3B**) (these inlets are sometimes used in animal facilities wider than 12–13 m).

The user navigates to the Pit + Barn option to properly locate the manure pit beneath the barn. This input process is identical to that described in Section "Inputs for Slotted-Covered Manure Pits beneath Tunnel-Ventilated Barns." The user has access to the same checks and balances described in Section "Checks, Balances, and Job Submission" prior to saving and submitting the project for CFD simulation.

Inputs for Slotted-Covered Manure Pits beneath Naturally Ventilated Barns

Two additional assumptions are imposed for simulating the ventilation of manure pits beneath naturally ventilated barns (**Figure 4**). The wind velocity is assumed to be 2.3 m/s. The wind direction is assumed to be plus or minus 45° from the direction perpendicular to the barn sidewalls (**Figure 4B**). The CFD simulation produces contaminant gas evacuation results for both wind directions.

After accessing the design aid as explained in Section "Accessing the Design Aid," the user first selects the naturally ventilated option. With the three previously described (see Inputs for Slotted-Covered Manure Pits beneath Tunnel-Ventilated Barns) input navigation buttons (Pit Geometry, Barn Geometry, and Pit + Barn), the user inputs in turn the required manure pit, barn, and barn + pit geometrical and ventilation system data. All data inputs for slotted-covered manure pits beneath naturally ventilated barns are identical to those listed in Section "Inputs for Stand-Alone Manure Pits" for stand-alone manure pits except those for the manure pit ventilation outlets. The slotted floor openings serve as the manure pit ventilation outlets for slotted-covered pits with barns above them.

To enter data for the naturally ventilated barn above the manure pit, the user selects the Barn Geometry navigation button. The user is then prompted with dialog boxes to enter the following barn information in turn:

- Barn roof eave and ridge heights (**Figure 4A**);
- Barn length (X-direction) and width (Y-direction);
- Curtain sidewall ventilation opening dimensions (**Figure 4A**);
- End wall openings: gable sheathing (yes or no); end wall sheathing (yes or no); and dimensions of up to five openings in sheathed end walls (**Figure 4B**);
- Continuous ridge ventilation air outlet width (**Figure 4A**);
- Location and size of natural ventilation flow obstructions on each sidewall and end wall (**Figure 4B**).

The user navigates to the Pit + Barn option to properly locate the manure pit beneath the barn. This input process is identical to that described in Section "Inputs for Slotted-Covered Manure Pits beneath Tunnel-Ventilated Barns." The user has access to the same checks and balances described in Section "Checks, Balances, and Job Submission" prior to saving and submitting the project for CFD simulation.

DESIGN AID SIMULATION RESULTS

Results Generated by Design Aid

The user is informed by email when SWFS® simulation results are available. This notification may occur within a few hours to a few days depending upon the size project and the number of projects submitted by other users at the same time. Simulation results are accessed by going to the design aid website identified in Section "Accessing the Design Aid" and selecting the project results desired (a user might have several submitted projects at any given time). Project-specific simulation results available to the user are (1) animations of contaminant gas concentrations as a function of manure pit ventilation time for several horizontal and vertical cross-sections (cut plots) in the manure pit and attached barn (**Figure 8**), (2) two-dimensional plots of maximum contaminant gas concentration inside the manure pit as a function of manure pit ventilation time (**Figure 9A**), (3) two-dimensional plots of maximum contaminant gas concentration inside attached barns as a function of manure pit ventilation time (**Figure 9B**), (4) two-dimensional plots of minimum oxygen concentration inside the manure pit as a function of manure pit ventilation time (**Figure 10A**), and (5) two-dimensional plots of minimum oxygen concentration inside attached barns as a function of manure pit ventilation time (**Figure 10B**). Two sets of animations and gas concentration decay or oxygen replenishment plots are provided for cases with naturally ventilated barns above slotted-covered manure pits: one for wind direction oriented 45° clockwise from the transverse building axis and the

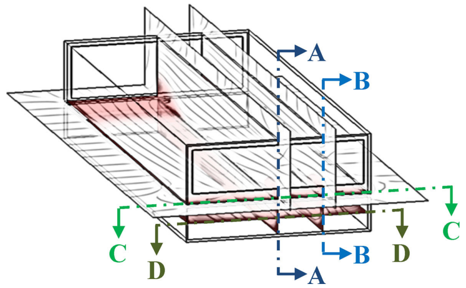

FIGURE 8 | **Definition of animation barn + pit cut-plot locations: vertical longitudinal section through center line (A–A); vertical longitudinal section at quarter point (B–B); horizontal section 152 mm above manure pit cover (C–C); and horizontal section at manure pit mid-height**.

other for wind direction oriented 45° counterclockwise from the transverse building axis (**Figure 4B**).

The contaminant gas and oxygen concentration animations are available for the horizontal and vertical cross-sections that are identified in **Figure 8**. Animations of gas concentration decay for several transverse vertical cross-sections are provided for cross-ventilated barns above slotted-covered manure pits. All animations are color coded per gas concentration level and uniquely so for each gas simulated (i.e., the color code for 1,000-ppm concentration is different for each gas). **Figure 11** presents the color code legend for each gas simulated. This gas-specific color coding was selected because of the large differences in typical concentrations of each gas in manure pits.

The plots of manure pit maximum gas concentration vs. ventilation time identify the pit ventilation time required to evacuate a contaminant gas concentration anywhere in the pit to below OSHA-defined PELs or ACGIH-defined TLVs, for example, the pit ventilation time required to reduce hydrogen sulfide concentration in the manure pit from the initial pit concentration to either OSHA-defined (2) PEL concentration of 10 ppm or ACGIH-defined (3) concentration of 1 ppm (**Figure 9A**). The PELs or TLVs for determining required pit ventilation times for long-term human occupancy are 1,000, 5,000, and 25 ppm, respectively, for methane, carbon dioxide, and ammonia (2, 3).

The plots of attached barn maximum gas concentration vs. ventilation time identify the maximum concentration of contaminant gases in the attached barn and the length of time the maximum contaminant gas concentration anywhere in the barn exceeds the gas-specific, short-term exposure limit (STEL) or short-time exposure ceiling limit. For example, the length of time the maximum hydrogen sulfide concentration exceeds either the OSHA-defined (2) short-time exposure ceiling limits of 20 ppm if there has been some prior hydrogen sulfide exposure or 50 ppm if there has been no prior hydrogen sulfide exposure (**Figure 9B**). The STELs selected in the design aid for evaluating the need to evacuate parts, or all, of the barn are, respectively, 25,000, 20,000, and 35 ppm for methane, carbon dioxide, and ammonia. The selected STEL for methane is 50% of the lower explosive limit (LEL). The selected STEL for carbon dioxide (20,000 ppm) is more conservative than the time-weighted average value

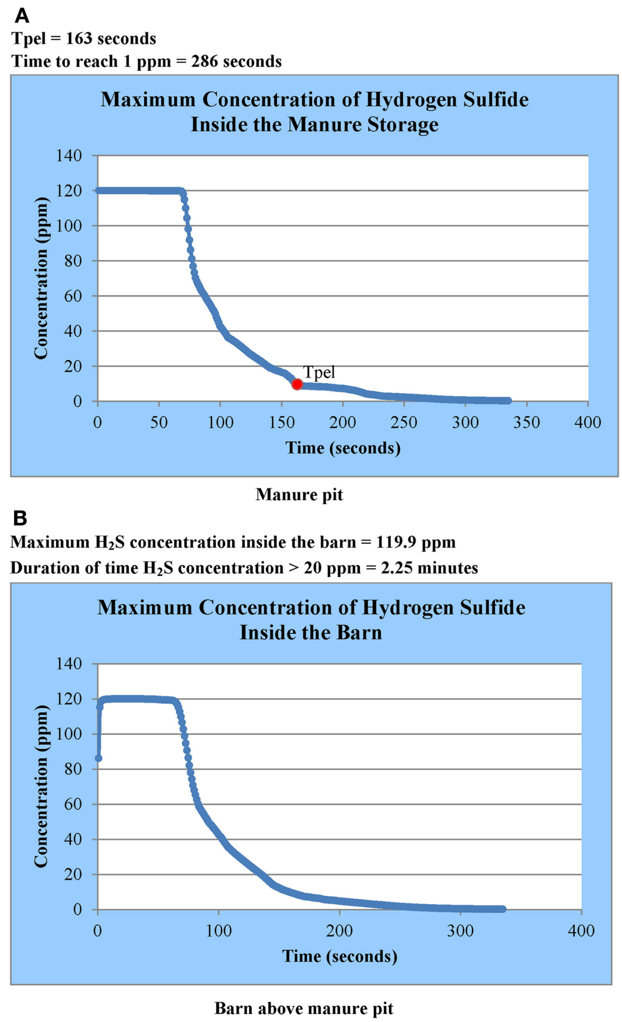

FIGURE 9 | **Hydrogen sulfide decay curves in (A) manure pit and (B) barn above the manure pit for Case Study 1: slotted-covered manure pit beneath a tunnel-ventilated (parallel flow) barn**.

(30,000 ppm). The selected STEL for ammonia (35 ppm) is more conservative than the OSHA-defined (2) TWA of 50 ppm. The user can adopt more or less conservative short-term exposure criteria for evacuation of all or portions of the barn by using the respective contaminant gas concentration decay curves and barn cut-plot animations.

The plots of oxygen replenishment during ventilation similarly identify the pit ventilation time required to increase oxygen concentration anywhere in the pit to the ACGIH-defined TLV of 19.5% by volume. The duration of time that oxygen levels anywhere in the barn are less than 19.5% by volume is specifically identified and highlighted (**Figures 10A,B**).

Applying Design Aid Results

For both stand-alone and slotted-covered manure pits beneath barns, the design aid results identify the required pit ventilation time to evacuate contaminant gases anywhere in the pit to below

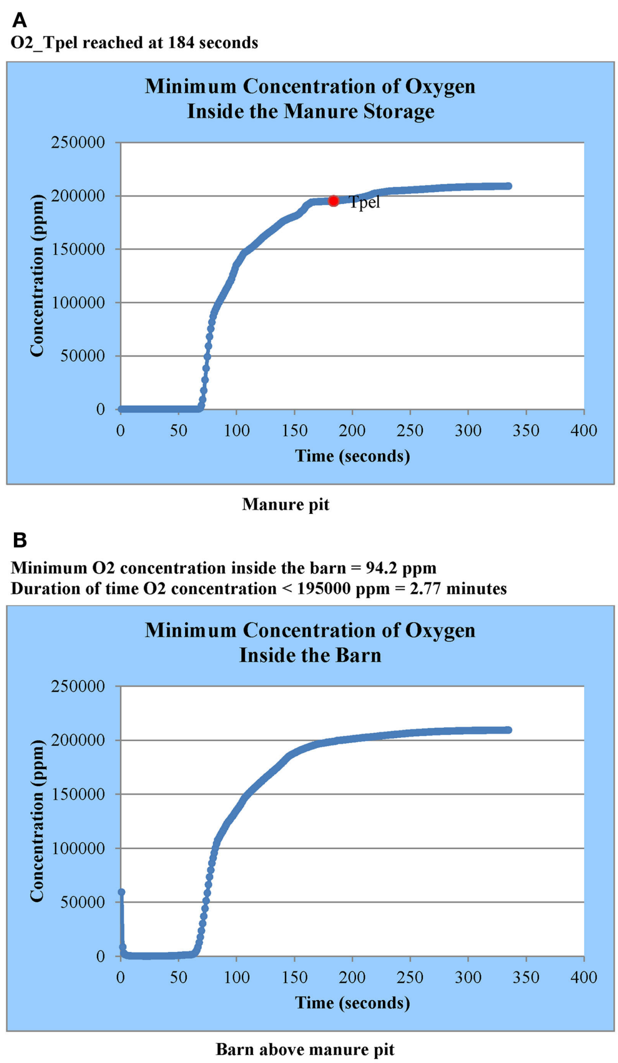

FIGURE 10 | Oxygen replenishment curves in (A) manure pit and (B) barn above the manure pit for Case Study 1: slotted-covered manure pit beneath a tunnel-ventilated (parallel flow) barn.

regulatory agency-defined levels for short-term and long-term human occupancy. It also defines the required pit ventilation time to replenish oxygen levels from 0 ppm to regulatory agency-defined levels for short-and long-term human occupancy. Agricultural building and manure pit designers and planners, as well as agricultural safety specialists and industrial hygienists, can use these design aid results to recommend minimum pit ventilation times and pit fan capacities to apply before human entry into the manure pit. The design aid can also be used to explore alternative pit ventilation design details – such as fan capacity, fan location, pit ventilation air outlet location, and the source of pit ventilation air (above pit or from a contaminant free area) for both temporary portable or permanent pit ventilation system applications.

For slotted-covered manure pits beneath any type of ventilated barn, the design aid results can be used to determine if any portion, or all, of the barn needs to be evacuated during a manure pit ventilation event. In addition, the design aid can be useful for evaluating alternative manure pit ventilation system configurations that minimize the degree of manure gas contamination in the barn during manure pit ventilation. For example, the designer might examine the effect of decreasing the manure pit ventilation rate, thereby increasing the time required to ventilate the pit, but reducing the proportion of the barn from which animals and personnel need to be evacuated. Or, the designer might alter the location of the manure pit ventilation fan to determine the best location for reduction of the contaminated zone in the barn.

A multiple-step evaluation of the simulation results is necessary to determine which portions, if any, of the barn needs to be evacuated prior to a manure pit ventilation event: (1) use the barn contaminant gas decay curves (**Figure 9B**) to determine if the maximum contaminant gas concentration exceeds the STEL, short-term ceiling limit, or other defined limiting concentration level, anywhere in the barn; (2) use the horizontal cross-section 150 mm above the slotted cover animations to determine which portions of the barn reach STEL, or other defined limiting levels, during the pit ventilation event (e.g., **Figure 12B**); and (3) use the vertical cross-section animations to determine the height of the zone, in which limiting gas concentrations are exceeded during the pit ventilation event (e.g., **Figure 12A**). Using this stepwise examination of the design aid results, the designer or safety specialist is able to make an informed decision about the degree of personnel and animal evacuations required prior to a manure pit ventilating event.

CASE STUDIES

Two case studies are presented. The first is for a slotted-covered manure pit beneath a tunnel-ventilated barn with two alternative manure pit ventilation configurations. The second is for a slotted floor covered manure pit beneath a mechanically cross-ventilated barn. Both case studies represent a typical manure pit beneath a fully stocked swine finishing barn.

Case Study 1: Slotted-Covered Manure Pit beneath a Tunnel-Ventilated Barn

The manure pit ventilation and gas evacuation simulation results for a slotted-covered manure pit beneath a tunnel-ventilated barn are now presented for two manure pit ventilation configurations (**Figure 2**). These results first illustrate simulation results for the two ventilation system. Then, the results are used to compare the performance of two alternative manure pit strategies to decide which one is the better option.

Case 1 Description – Parallel and Counter Flow

This case study is for a 12.2-m wide by 30.5-m long by 3.05-m ceiling height swine barn for 450 finishing pigs above a totally slotted-covered 12.2-m wide by 30.5-m long by 2.44-m deep manure pit. The barn negative pressure ventilation capacity, 226.0 m^3/s, is the design hot weather ventilation rate for 450

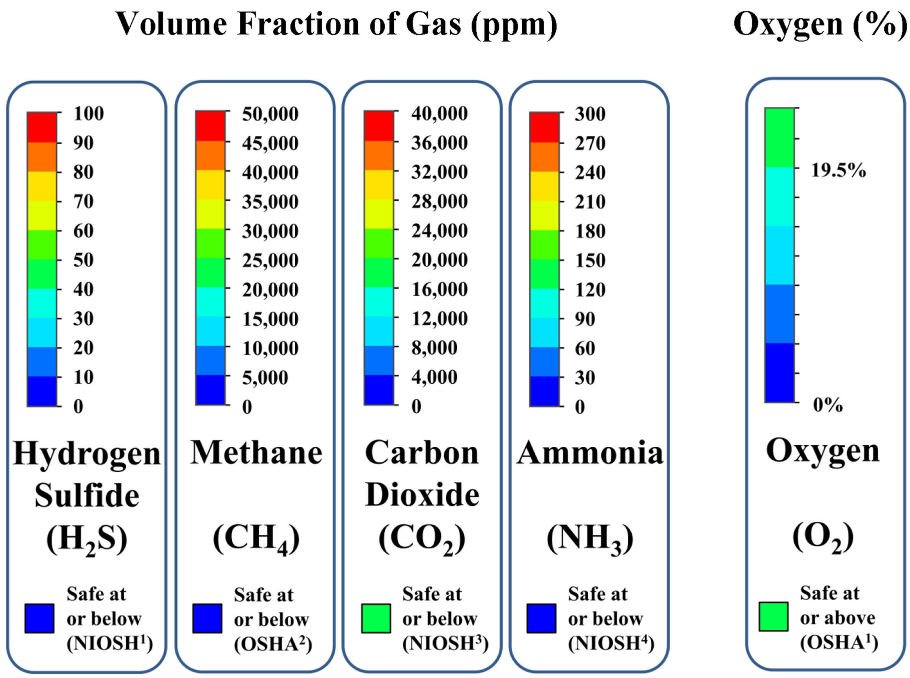

FIGURE 11 | Color code legends for interpreting animations of gas concentrations in the manure pit or barn as function of time from commencement of pit ventilation. Red indicates that contaminant gas concentration above potentially lethal limit; blue indicates that contaminant gas concentration is below its TLV or PEL. Green indicates that oxygen levels are 19.5% or higher; blue indicates that oxygen level of 0% by volume.

finishing pigs (9, 15). Initial manure pit gas concentrations are 120, 85,000, 70,000, 300, and 0 ppm, respectively, for hydrogen sulfide, methane, carbon dioxide, ammonia, and oxygen.

The manure pit is ventilated with a 610-mm diameter, 4.5 m^3/s pit fan located 6.10 m from the sidewalls and 610 mm from either the end wall containing the barn ventilation exhaust fans or the end wall containing the barn ventilation air inlets. The first pit fan location is characterized as parallel flow (**Figure 2B**), and the latter as counter flow (**Figure 2C**). In both air flow cases, the pit fan directs recirculated barn air from directly above the slotted-cover into the pit perpendicular to the slotted-cover plane.

Hydrogen Sulfide Decay Concentration Curves (Pit and Barn) – Parallel Flow

Figure 9A is the simulated hydrogen sulfide decay curve for the manure pit for the parallel flow case. The decay curve is not for a particular location in the pit. Instead, it is a plot of the maximum concentration anywhere in the manure pit domain as a function of manure pit ventilation time. The legend in **Figure 9A** identifies and **Table 1** lists the ventilation time required to reduce the maximum pit hydrogen sulfide concentration to either the OSHA-defined level of 10 ppm (163 s) or the ACGIH-defined level of 1 ppm (286 s).

Figure 9B is the simulated hydrogen sulfide decay curve for the barn for the parallel flow case. Again, the decay curve shows the maximum hydrogen sulfide concentration in the barn domain as a function of manure pit ventilation time. The figure legend identifies and **Table 1** lists the maximum hydrogen sulfide level anywhere in the barn domain and the time period that the maximum hydrogen sulfide is above the OSHA-defined ceiling limit of 20 ppm (135 s) (2) The decay curves do not identify the zones of the barn for which hydrogen sulfide concentrations exceed the ceiling limit. The barn contamination zones are identified by examination of the cut-plot animation of hydrogen sulfide concentrations through the horizontal plane 152 mm above the slotted cover.

Hydrogen Sulfide Cut Plots – Parallel Flow

Figure 12 shows the frames of three hydrogen sulfide concentration animations 10 s after the commencement of pit ventilation. The animations are for, respectively, the vertical plane through the barn and pit longitudinal axis (**Figure 12A**), the horizontal plane 150 mm above the slotted cover (**Figure 12B**), and the horizontal plane located at the pit mid-height (**Figure 12C**). These frames clearly identify the zones (those colored zones ranging from light blue to red), in which hydrogen sulfide concentrations exceed the 20-ppm ceiling exposure limit during pit ventilation. For the case study barn and parallel flow ventilation configuration, the zone of barn contamination exceeding 20 ppm is confined to one located within 10.8 m of the end wall containing the barn exhaust ventilation fans. If the less conservative short-term ceiling exposure limit of 50 ppm is selected, only those barn zones within 6.1 m (those colored zones ranging from green to red) of the end wall containing the barn fans need to be evacuated (**Figure 12B**).

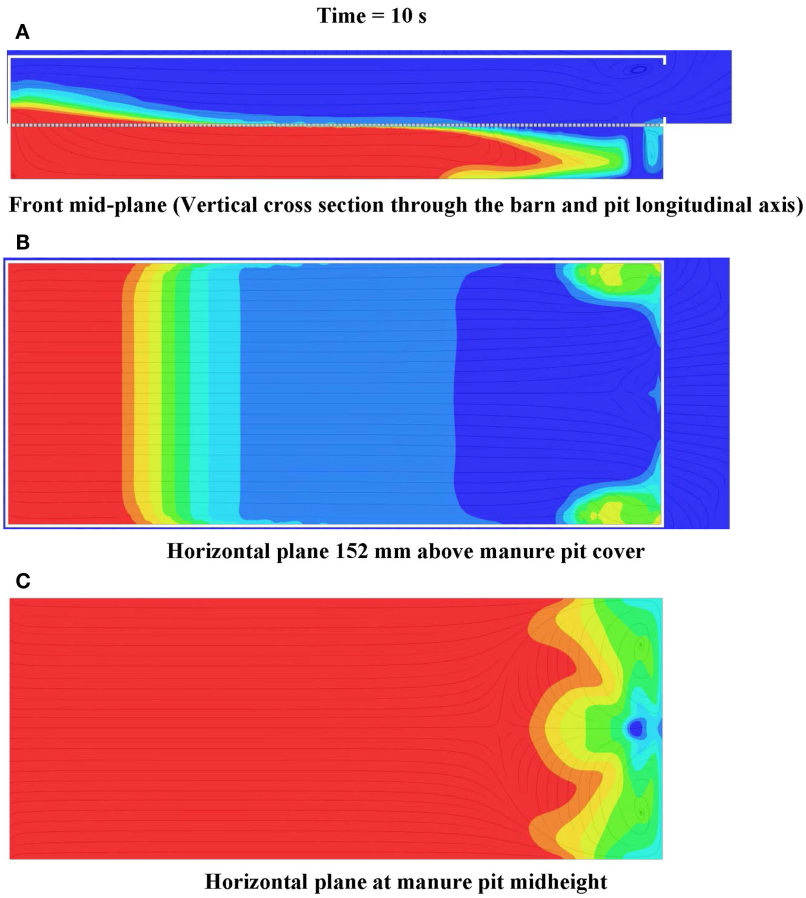

FIGURE 12 | **Frames of (A) front mid-plane, (B) horizontal plane 152 mm above manure pit cover, and (C) horizontal plane at manure pit mid-height cut plot animations of hydrogen sulfide concentration 10 s after commencement of pit ventilation for Case Study 1: tunnel ventilated (parallel flow) barn above slotted-covered manure pit (see Figure 11 for color legend for hydrogen sulfide).**

TABLE 1 | Case 1 simulation results for hydrogen sulfide, methane, carbon dioxide, and ammonia: slotted-covered manure pit beneath tunnel-ventilated barn – parallel flow.

Gas	Initial pit gas concentration (ppm)	Pit ventilation time to reach TLV or PEL[a] (s)	Maximum gas concentration in barn (ppm)	Pit ventilation time to reach limiting gas concentration in barn[b] (s)
Hydrogen sulfide	120	163 (10 ppm) 286 (1 ppm)	119	135
Methane	85,000	275	84,962	109
Carbon dioxide	70,000	174	69,969	109
Ammonia	300	163	300	145

[a]PEL for hydrogen sulfide is either 1 or 10 ppm; TLV for methane is 1,000 ppm; PEL for carbon dioxide is 5,000 ppm; and TLV for ammonia is 25 ppm (2, 3).
[b]Short-term ceiling limit for hydrogen sulfide is 20 ppm (2); investigator-defined limiting concentration is 25,000 ppm for methane, 20,000 ppm for carbon dioxide, and 25 ppm for ammonia (see Results Generated by Design Aid).

Oxygen Replenishment Curves in (Pit and Barn) – Parallel Flow

Figure 10A is the simulated oxygen replenishment curve for the manure pit for the parallel flow case. The replenishment curve is not for a particular location in the pit. Instead, it represents the minimum concentration anywhere in the manure pit domain as a function of manure pit ventilation time. The legend identifies the ventilation time required to replenish pit oxygen concentration in the entire pit to the ACGIH-defined TLV of 19.5% (184 s).

Figure 10B is the simulated oxygen replenishment curve for the barn for the parallel flow case. Again, the plot shows the minimum oxygen concentration in the barn domain as a function of manure pit ventilation time. The figure legend identifies the minimum oxygen concentration level anywhere in the barn domain and the time period that the minimum oxygen concentration is less than 19.5% by volume (166 s). The replenishment curves do not identify the zones of the barn for which oxygen concentrations are less than 19.5%. These zones are identified by examination of the horizontal barn cut-plot animations of oxygen concentration as described in Section "Hydrogen Sulfide Cut Plots – Parallel Flow" for hydrogen sulfide.

Simulation Results for Other Contaminant Gases (Pit and Barn) – Parallel Flow

Table 1 reports the simulation results for all contaminant gases for the parallel flow case study. Simulation results for methane, carbon dioxide, and ammonia were obtained from gas decay curves similar to those presented in Section "Hydrogen Sulfide Decay Concentration Curves (Pit and Barn) – Parallel Flow" for hydrogen sulfide.

Simulated ventilation times to evacuate contaminant gases in the manure pit to below PELs or TLVs for the case study geometry, ventilation configuration, and ventilation rates are 275, 174, and 163 s, respectively, for methane, carbon dioxide, and ammonia. Maximum barn contaminant gas concentrations approach the initial concentrations somewhere in the barn during the first few seconds after commencement of pit ventilation. Methane, carbon dioxide, and ammonia concentrations in the barn exceed the previously defined short-term limiting concentrations for 109, 109, and 145 s, respectively. The horizontal and vertical cut-plot animations of contaminant gas concentrations in the barn show a pattern almost identical to that shown earlier for hydrogen sulfide. The barn zone within approximately 10.8 m of the end wall containing the barn exhaust fans is the only one with contaminant gas concentrations exceeding the short-term limits.

Selected Simulation Results for Tunnel-Ventilated Case Study with Counter Flow Ventilation

Only the results for hydrogen sulfide are presented for the slotted-covered manure pit beneath a counter flow ventilated (**Figure 2C**) barn. The required pit ventilation times to evacuate hydrogen sulfide to 10 and 1 ppm, taken from the simulated manure pit gas decay curve, are 510 and >737 s, respectively. The design aid sometimes terminates the simulation when, as in this case, the hydrogen sulfide manure pit concentration approaches 1 ppm nearly asymptotically. This avoids excessive computer run time. Examination of the hydrogen sulfide decay curve for this case study example clearly showed that a pit ventilation time of approximately 750 s is a satisfactory ventilation time for evacuation of hydrogen sulfide in the pit to approximately 1 ppm. From the simulated barn gas decay curve, hydrogen sulfide concentrations in the barn exceed the OSHA-defined (2006) ceiling limit of 20 ppm for 315 s. **Figures 13A-C** are frames from three animations of hydrogen sulfide concentrations in the pit and barn 10 s after commencement of pit ventilation. **Figure 13A** is for a vertical cross-section through the barn and pit longitudinal centerline; **Figure 13B** is for the horizontal plane 150 mm above the slotted cover; **Figure 13C** is for the horizontal plane at the pit mid-height. The frames clearly show (the colored zone ranging from light blue to red) that the barn zones in which hydrogen sulfide concentration is greater than 20 ppm extend 12.2 m from the end wall containing the barn ventilation fans. If the less conservative ceiling limit of 50 ppm is selected, only those barn zones within 10.5 m (those colored zones ranging from green to red) of the end wall containing the barn fans need to be evacuated (**Figure 13B**).

The ventilation times to evacuate hydrogen sulfide to 10 and 1 ppm in the manure pit are 312% (510 vs. 163 s) and more than 257% (>737 vs. 286 s) greater, respectively. The time period during which hydrogen sulfide concentrations in the barn exceed 20 ppm are 233% (315 vs. 135 s) greater for counter flow ventilation compared to the parallel flow manure pit ventilation configuration. The zone in which barn contamination exceeds the OSHA-defined short-term ceiling limit of 20 ppm is also 12% larger (12.1 vs. 10.8 m from the end wall containing the barn fans) for the counter flow configuration compared to the parallel flow configuration. The design aid shows that the parallel flow configuration is clearly the better one for ventilating this manure pit and barn.

Case 2: Slotted-Covered Manure Pit beneath a Cross-Ventilated Barn

Case Study 2 is a simulation of the same 12.2-m wide by 30.5-m long slotted-covered manure pit beneath a barn of the same size used in Case 1 (see Case 1 Description – Parallel and Counter Flow) (**Figure 3**). The initial manure pit gas concentrations are the same except initial methane and carbon dioxide concentrations are 70,000 and 85,000 ppm, respectively. The pit fan size and capacity, and the source and direction of manure pit ventilation air are identical to Case Study 1. The only differences between Case Studies 1 and 2 are the location of the pit fan and the configuration of the barn ventilation system.

The 610-mm (4.5 m^3/s) diameter pit fan is located in the slotted floor at a location along the transverse centerline of the barn and offset 1.22 m from the sidewall opposite the barn fans (**Figure 3A**). The pit fan air supply is taken from directly above the slotted cover; the pit fan directs air downward at an angle 90° from the manure pit cover.

The ventilation system for the cross-vented barn consists of three identical and uniformly spaced 1.32-m diameter negative pressure fans located on one sidewall and 203-mm wide slotted air inlets located along the entire eave length of both sidewalls. The total AC of the three barn ventilation fans is 26.0 m^3/s. The first fan is offset 6.10 m from one end wall; the last sidewall fan is offset 6.1 m from the other end wall.

Contaminant Gas Concentration Decay and Oxygen Replenishment Curve Results: Cross-Ventilated Barn

Table 2 reports the simulation results for all contaminant gases for the cross-ventilated case study. Simulation results for hydrogen sulfide, methane, carbon dioxide, and ammonia were obtained from gas decay curves similar to those presented in Section "Contaminant Gas Concentration Decay and Oxygen Replenishment Curve Results: Cross-Ventilated Barn" for hydrogen sulfide decay in tunnel-ventilated barns (**Figures 9A,B**). The cross-ventilated decay curves are not shown for brevity.

The ventilation time required to reduce the maximum manure pit hydrogen sulfide concentration from 120 ppm to the OSHA-defined level of 10 ppm is 303 s; and the corresponding ventilation time to evacuate hydrogen sulfide to the ACGIH-defined level of 1 ppm is >549 s. The design aid sometimes terminates the simulation when, as in this case, the hydrogen sulfide manure pit concentration approaches 1 ppm nearly asymptotically. This avoids excessive computer run time. Examination of the hydrogen sulfide decay curve for this case study example clearly showed that a pit ventilation time of 540 s is a satisfactory ventilation time for evacuation of hydrogen sulfide in the pit to approximately 1 ppm. Simulated ventilation times to evacuate the remaining manure pit contaminant gas concentrations to below PELs or TLVs for the case study geometry, ventilation configuration, and ventilation

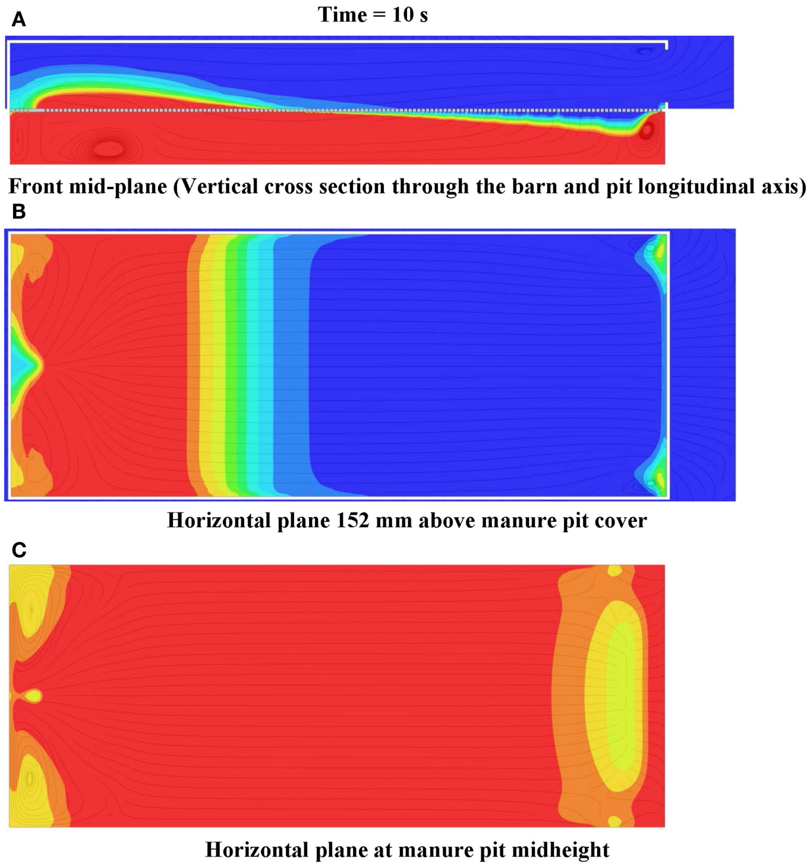

FIGURE 13 | Frames of (A) front mid-plane, (B) horizontal plane 152 mm above manure pit cover, and (C) horizontal plane at manure pit mid-height cut plot animations of hydrogen sulfide concentration 10 s after commencement of pit ventilation for Case Study 1: tunnel ventilated (counter flow) barn above slotted-covered manure pit (see Figure 11 for color legend for hydrogen sulfide).

TABLE 2 | Case 2 simulation results for hydrogen sulfide, methane, carbon dioxide, and ammonia: slotted-covered manure pit beneath cross-ventilated barn.

Gas	Initial pit gas concentration (ppm)	Pit ventilation time to reach TLV or PEL[a] (s)	Maximum gas concentration in barn (ppm)	Pit ventilation time to reach limiting gas concentration in barn[b] (s)
Hydrogen sulfide	120	303 (10 ppm) >549 (1 ppm)	119	182
Methane	70,000	523	69,612	119
Carbon dioxide	85,000	351	84,528	156
Ammonia	300	303	298	223

[a]PEL for hydrogen sulfide is either 1 or 10 ppm; PEL for methane is 2,500 ppm; PEL for carbon dioxide is 5,000 ppm; and PEL for ammonia is 25 ppm (2, 3).
[b]Short-term ceiling limit for hydrogen sulfide is 20 ppm (2); investigator-defined limiting concentration is 25,000 ppm for methane, 20,000 ppm for carbon dioxide, and 25 ppm for ammonia (see Results Generated by Design Aid).

rates are 523, 351, and 303 s, respectively, for methane, carbon dioxide, and ammonia.

The maximum contaminant gas concentration in the barn domain as a function of manure pit ventilation time was obtained from contaminant gas decay curves similar to **Figure 11B**. **Table 2** lists the maximum hydrogen sulfide level anywhere in the barn domain and the time period that the maximum hydrogen sulfide is above the OSHA-defined ceiling limit of 20 ppm (182 s). Methane, carbon dioxide, and ammonia concentrations in the barn exceed the previously defined short-term limiting concentrations for 119, 156, and 223 s, respectively. **Table 2** also lists the maximum contaminant gas concentrations in the barn during manure pit ventilation. Maximum barn contaminant gas concentrations approach the initial manure pit concentrations somewhere in the barn during the first few seconds after commencement of pit ventilation.

From oxygen replenishment curves similar to those shown in **Figure 10A** for the Case 1 slotted-covered manure pit beneath a tunnel-ventilated barn, the ventilation time required to replenish oxygen concentration in the entire pit to 19.5% by volume is 327 s. From oxygen replenishment curves similar to those shown in **Figure 10B**, the time period that the minimum oxygen concentration in the barn is below the ACGIH-defined TLV of 19.5% by volume is 295 s.

The barn contaminant gas decay and oxygen replenishment results alert the user that animals and personnel need to be evacuated from portions of the barn before pit ventilation commences. The cut-plot animations of gas concentration need to be inspected to determine which zones require evacuation.

Contaminant Gas Cut-Plot Results: Cross-Ventilated Barn

Figures 14A,B are frames from the simulated hydrogen sulfide animations 10 s after commencement of manure pit ventilation for, respectively, the horizontal plane 150 mm above the slotted cover and the horizontal plan at the manure pit mid-height. **Figures 15A,B** are similar 10-s animation frames for the vertical plane through the longitudinal centerline of the barn and pit, and the transverse vertical plane at the transverse centerline of the barn and pit. These frames clearly identify the zones (those in light blue to red), in which hydrogen sulfide concentrations exceed the 20-ppm ceiling limit during pit ventilation. For the barn and pit ventilation configuration and initial conditions of the cross-ventilated case study barn and barn cross-ventilated configuration, the zone of barn contamination exceeding the ceiling limit is extensive and scattered throughout the barn footprint and throughout large portions of the vertical barn profile. The horizontal and vertical cut-plot animations of methane, carbon dioxide, and ammonia concentrations in the barn show a pattern almost identical to that shown for hydrogen sulfide. That is, the zone of barn contamination exceeding the previously defined short-term limits is extensive (more than 80% of the total footprint area) and scattered throughout the barn footprint.

Case Study 2 Closure

For the case study barn and pit ventilation configuration and initial conditions, animals and personnel need to be evacuated from the entire barn prior to manure pit ventilation. Alternatively, the design professional or regulatory personnel could use the design aid to simulate alternative manure pit and/or barn ventilation strategies. Potential alternative strategies include pit fan location, pit fan air flow direction, pit fan air supply ducted from non-contaminated fresh air source, and strategic blocking of barn ventilation air inlets. If no combination of alternative pit and/or ventilation strategies satisfactorily limits the barn contamination, then the only alternative is to evacuate animals and personnel from the barn before ventilating the manure pit.

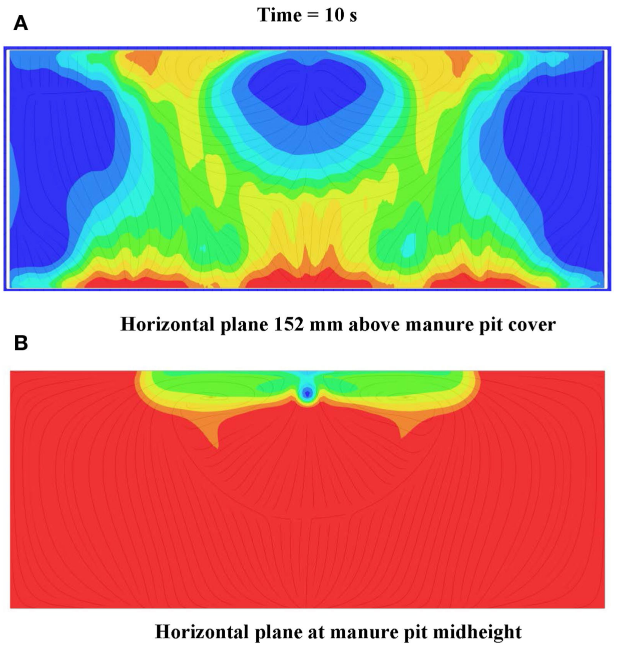

FIGURE 14 | **Frames of (A) horizontal plane 152 mm above manure pit cover, and (B) horizontal plane at manure pit mid-height cut plot animations of hydrogen sulfide concentration 10 s after commencement of pit ventilation for Case Study 2: cross-ventilated barn above slotted-covered manure pit (see Figure 11 for color legend for hydrogen sulfide).**

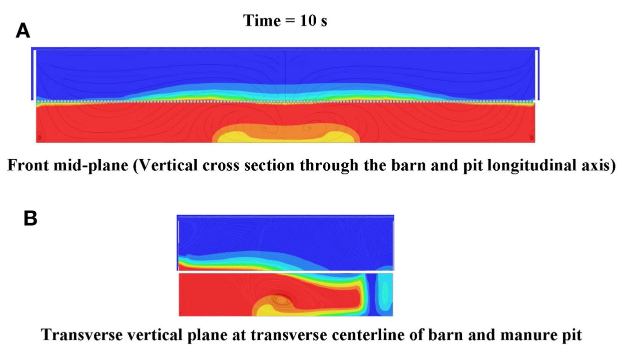

FIGURE 15 | **Frames of (A) front mid-plane and (B) transverse vertical plane at centerline of barn and pit cut plot animations of hydrogen sulfide concentration 10 s after commencement of pit ventilation for Case Study 2: cross-ventilated barn above slotted-covered manure pit (see Figure 11 for color legend for hydrogen sulfide).**

DISCUSSION

The described design aid simulation protocols and results are useful for determining when contaminant gas concentrations have been evacuated from the entire manure pit, or portions thereof, to levels suitable for human entry. The results therefore are useful for defining the portions of the manure pit that can be entered for planned repair and maintenance or for emergency situations even when self-contained breathing equipment is not available to personnel. This is important because few farms have such equipment (16). However, many do have access to fans and blowers for pit ventilation prior to an entry event.

The online tool is a pre-and post-processing software that interfaces typical manure pit and barn configurations and ventilation configurations with modern CFD and CAD software. The tool is particularly useful to users who use CFD software infrequently and cannot justify purchasing software licenses for only a few projects annually. The developed online tool offers a user-friendly, cost-effective alternative for these users.

The online design aid results are not intended to replace the need to continuously monitor confined-space manure pits for contaminant gases and oxygen content prior to and during an entry event. It is recommended that all entry events be conducted by (1) monitoring contaminant manure pit gas and oxygen levels prior to pit ventilation; (2) ventilating the pit at the rates and for the time defined by the design aid simulations; (3) monitoring contaminant gas levels during pit ventilation until all contaminant gas levels are below the TLVs or PELs for hydrogen sulfide, carbon dioxide, methane, and ammonia, and oxygen levels reach 19.5% by volume; and (4) continuing to ventilate the pit and monitor contaminant and oxygen levels during the entire entry event.

The design aid simulation protocols are also useful to determine from which, if any, portions of barns above slotted-covered manure pits animals and personnel need to be evacuated prior to a pit ventilation event. The design aid is useful, also, for determining the maximum manure pit contamination gas levels below which such evacuation is not necessary. Such information is valuable because evacuation of animals often is a very time consuming and costly operation.

The current version of the online design tool does not include the influence of airflow obstructions, such as equipment, partitions, and animals, in the barn above a slotted-covered manure pit. Such obstructions would not influence the manure pit contaminant gas evacuation or oxygen replenishment times in the manure pit. However, the portions of the barn which need to be evacuated may be altered if these obstructions are extensive.

The design aid, including the input- and results-processing routines and the CFD software, is hosted on a Pennsylvania State University server. The online design aid is currently available to users at no cost. In the future, the design aid will be available to users either at no cost or for the cost of computer project simulation run time. This is extremely cost-effective, especially for the designer, planner, or regulatory personnel that only requires manure pit CFD simulations a few times each year.

AUTHOR CONTRIBUTIONS

HM: served as technical advisor to the project, especially for those aspects related to animal housing design, ventilation of animal housing systems, and manure pit layout. DH: developed protocols to collect and transform user project data into format compatible with SWFS; also developed protocols for extracting and reporting SWFS simulation outcomes; and also established the parameters under which SWFS simulations were conducted. DM: served as project director; provided oversight for all project activities; and provided technical guidance on the safety and regulatory issues related to the project. VP: provided technical guidance on project issues related to various aspects of numerical modeling, computer modeling, and computer simulation.

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Dairy Tool Box Talks: A Comprehensive Worker Training in Dairy Farming

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Today's dairies are growing rapidly, with increasing dependence on Latino immigrant workers. This requires new educational strategies for improving milk quality and introduction to state-of-the-art dairy farming practices. It also creates knowledge gaps pertaining to the health of animals and workers, mainly due to the lack of time and language barriers. Owners, managers, and herdsmen assign training duties to more experienced employees, which may not promote "best practices" and may perpetuate bad habits. A comprehensive and periodic training program administered by qualified personnel is currently needed and will enhance the sustainability of the dairy industry. Strategic management and employee satisfaction will be achieved through proper training in the employee's language, typically Spanish. The training needs to address not only current industry standards but also social and cultural differences. An innovative training course was developed following the same structure used by the engineering and construction industries, giving farm workers basic understanding of animal care and handling, cow comfort, and personal safety. The "Dairy Tool Box Talks" program was conducted over a 10-week period with nine sessions according to farm's various employee work shifts. Bulk milk bacterial counts and somatic cell counts were used to evaluate milk quality on the three dairy farms participating in the program. "Dairy Tool Box Talks" resulted in a general sense of employee satisfaction, significant learning outcomes, and enthusiasm about the topics covered. We conclude this article by highlighting the importance of educational programs aimed at improving overall cross-cultural training.

Keywords: dairy farm trainings, Spanish training, Latino worker, migrant worker, milk quality, dairy sustainability, tool box talks, educational training

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INTRODUCTION

Today's dairy farms are changing dynamically, with increasing herd size and more hired employees. On larger U.S. farms, there is a reliance on non-family immigrant or contract laborers. Latinos have surpassed African-Americans as the nation's largest minority group, constituting 17% of the U.S. total population in 2014 (1). This is reflected within the dairy industry, and the increasingly Latino workforce requires adapted educational strategies for training. Additionally, the dairy industry sustains high occupational injury rates due to the handling of large animals and highly repetitive tasks demanded from dairy milking parlor workers (2). Lack of effective training strategies creates many knowledge gaps pertaining to both animal and worker health.

A dairy farm involves many day-to-day activities that include animal care, breeding, crop production and feed preparation, cleaning and waste management, and most importantly, milking. Multiple factors interfere with milk quantity and quality (e.g., genetics, environment, and livestock management practices). One of the most costly diseases in dairy farming is intramammary infection or mastitis (3). Bacterial infection is the most common cause of mastitis. High somatic cell counts (SCC) correlate to mastitis and negatively affect milk quality, the cow's production, and ultimately the profitability of the dairy. Bulk tank milk (BTM) SCC indicate the number of infected animals in the herd as well as the expected decrease in milk yield and quality (4). Mastitis prevalence can be reduced by good cow management, which is established by effective training (5).

In the increasingly immigrant-based large dairy workforce in South Dakota, parlors have an intensive schedule of milking 24 h/day with brief interludes for cleaning. This schedule requires varied shifts, demanding high physical exertion. Many dairy farms, especially those milking cows three times per day, operate by two 12-h working shifts daily. The majority of farm workers have neither basic education nor knowledgeable experience pertaining to dairies (5). In this context, factors, such as socioeconomics, education, cultural diversity, and English proficiency, have enormous impacts on worker understanding of day-to-day tasks, which greatly affect work goals (6).

There is a significant gap in knowledge between dairy professionals and dairy owners regarding employee training. Additionally, employee turnover is costly for most dairy employers. For this reason, the dairy industry needs to restructure the available educational programs for laborers. The engineering and construction industries have successfully implemented targeted innovative employee trainings to improve worker safety and operational efficiency (7, 8). This perspective article focuses primarily on the design procedure of similar innovative training courses by a strategic approach to environmental sustainability, animal health and well-being, milk quality practices, and worker health within the dairy industry. Furthermore, we highlight the potential importance of developing a comprehensive training program in the worker's native language to address not only current industry standards in dairy farming but also social and cultural differences, leading to a more equitable and sustainable industry for a safe, economical food supply.

THE TRAINING STRUCTURE

The study was conducted during a 3-month period, from June until August, 2015, at three commercial dairies in eastern South Dakota, each with 1,600–2,700 Holstein and crossbred Holstein cows (Farm A, Farm B, and Farm C). During the period of study, average milk yield was 33 kg/cow/day, and the monthly bulk milk SCC ranged on average from 159,000 to 270,000 cells/mL.

The target dairy workers were primarily Spanish-speaking Latino migrant workers. Seventy-five people related to milking operations, cow handling, and bedding/hospital pen cleaning participated in the program.

Innovative within the dairy industry, the program was based on trainings used by the engineering and construction industries. Called the "Dairy Tool Box Talks," weekly trainings were conducted with dairy employees in Spanish. The program talks were conducted over a 10-week period and included a 1-h hands-on with live cattle and eight trainings of 30-min classroom-style covering the following topics:

1. Basic cow and milk production knowledge.
2. Basic cow housing and facilities overview.
3. Animal health and cleanliness: cow signals.
4. Consistent and proper milking procedures.
5. Mastitis and SCC.
6. Safe hands-on cow handling (1 h).
7. Cultural differences within the labor place.
8. Animal welfare and risks of animal organization.
9. Zoonosis and using good ergonomics.

For each session, a PowerPoint presentation was prepared to provide more effective presentations and a better understanding of the topics presented. The use of interactive games, drama activities, and also invited speakers were used to improve the employees' understanding of the different topics covered during the program sessions. Participants received a one-page handout in Spanish with detailed information on the week's topic at each session.

A final evaluation session for employee group feedback and certification was conducted at week 10 using Turning Technologies® (data not shown) and flipcharts to interactively convey information and discuss their impressions of the program. Most of the dairy workers involved in the "Dairy Tool Box Talks" participated in the feedback session. At the end of the training period, a feedback session was also provided to the owners, managers, and herdsmen to discuss their impressions of the program and any employee improvements observed.

Sample Collection, Laboratory Determinations, and Statistical Analysis

Bulk tank analysis is a useful screening tool used to monitor specific problem areas within the dairy farm, identify weak management protocols, and provide useful information on SCC.

For microbiologic activity determination, 50-mL BTM samples were taken on three consecutive days each week and combined. Samples were stored at −20°C until analyzed at the Animal Disease Research and Diagnostic Laboratory at South Dakota State University (Brookings) according to reference microbiology methods for BTM.

Composite weekly samples were cultured on selective media, and colonies were identified using preliminary biochemical and selective media tests. Colonies were grown overnight at 37°C on tryptic soy agar (Remel Inc.) infused with 5% sheep blood or brain–heart infusion agar, mannitol salt agar, MacConkey agar, and modified Edward agar. Samples were identified through matrix-assisted laser desorption/ionization and time-of-flight (MALDI-TOF) mass spectrometry (MALDI Biotyper; Bruker Daltonics Inc., Billerica, MA, USA) when necessary.

Bulk Tank Milk for somatic cell count (BTSCC) were collected daily at each farm by a licensed milk hauler and reported to the researchers. Data of BTSCC and microbiology identification results were log (base 10) transformed to normalize the data before analysis using the PROC MIXED (version 9.3; SAS Institute Inc., Cary, NC, USA). A mixed procedure for repeated measurements was used for BTSCC data and included the fixed effect of farms and time relative to training (weeks 1–10) and the random effect of tank sampling within farm. The mixed model used for the bacteriology identification results included the fixed effects of the farms and the training period, which was classified as start, mid, and final sessions (1–3, 4–6, and 7–10, respectively), and the random effect of tank sampling within farm. Significance was declared at $p < 0.05$, unless otherwise indicated.

THE LEARNING INNOVATIVE APPROACH

In 2016, the gap between non-fluent English and Native English speaking dairy farm personnel is greater than ever. The inability to communicate has consequences in producing a safe food supply while contributing to the sustainability of the dairy industry. The agriculture sector in the U.S. recognizes that foreign-born workers are increasingly becoming a vital part of the community and the local workforce, especially in the dairy industry. Immigrant workers account for over 50% of all U.S. dairy labor which produces over 79% of the U.S. milk supply (9). It was estimated that 41% of the dairy labor force was immigrants with the majority coming from Mexico (10). Evidence from the American Farm Bureau (AFB) (11) suggests the number of immigrant laborers may be even greater than the estimates.

The owners of large dairy enterprises are business savvy and not the traditional reactive farmers of the past. Today's proactive owners oversee the health and safety of their employees and ensure consistent, safe care of the cows, which in turn positively impacts the milk production and quality (e.g., minimizing mastitis cases), while also minimizing injuries to workers in this high-risk industry. However, few dairies have active worker training programs that meaningfully educate workers about key principles of livestock care and follow up with evaluations of performance at periodic intervals (12).

The most common source of on-farm training has been the traditional format commonly offered by University Extension Programs. This provides unbiased non-formal education and learning activities to a wide range of people, including agricultural producers and their employees. Other training opportunities through pharmaceutical, nutrition, and reproduction service companies are also offered, but this type of training is biased and limited in duration and impact. The effectiveness and feasibility of training transfer by these two mechanisms is difficult to determine. Non-English speaking employees are hesitant to ask questions during single-session trainings due to their cultural upbringing. Without recognizing this cultural difference within the dairy employees, the one-time training session is an ineffective training tool.

New training approaches implementing appropriate on-farm management practices with short periodic trainings in Spanish will enhance sustainability of the dairy industry by enhancing milk quality, decreasing milk loss, improving dairy cows' health, and reducing employee injuries/illnesses. Additionally, farms will see improvement in worker's performance due to a decrease in days off from worker injury or illness and enhanced job performance due to increased knowledge, impacting job performance. Cultural consideration is central to training design and implementation. The "Dairy Tool Box Talks" was designed to provide efficient short-duration hands-on educational demonstrations analogous to tool box talks and pre-task planning in the construction industry. Sessions covered basic modern dairy operation, including basic animal care and handling practices, cow comfort awareness and worker welfare, proper milking protocols, and worker safety. Educational topics focused on preventing zoonosis, managing risks of animal organization, and important cultural differences.

The production of high quality milk is a requirement to sustain a profitable dairy industry, and SCC values are routinely used to identify subclinical mastitis and define quality standards (13). Mastitis is one of the three most significant health problems of the worldwide dairy herds, together with lameness and fertility problems (14) and is the most costly disease of the dairy industry (15). Mastitis has important effects increasing SCC as well as in reducing other milk components (e.g., protein and fat levels and its impact on cheese manufacturing). In the U.S., the legal maximum BTSCC for liquid market (Grade A milk) shipments is 750,000 cells/mL, as outlined in the U.S. Pasteurized Milk Ordinance (16, FDA-PMO, 2011), and a threshold of <200,000 cells/mL is considered to be of the most practical value used to define a mammary quarter as healthy (13). In this research, BTSCC values were recorded each week throughout the training sessions to measure milk for quality indicators and to monitor the dynamics of possible decrease in intramammary infections due to a proper training. **Table 1** shows the average BTSCC milk composition for all three farms, where the average values were significantly different ($p < 0.001$) within farms. The difference in BTSCC levels between farms can be explained by individual differences between cows of each farm and by differences in management practices and consistency that may increase the number of intramammary infections within the herd. The observed trends in milk BTSCC for the participant farms were below the accepted threshold for Grade A milk. Farm A and C were within the range of a more healthy herd, whereas Farm B reached values above 250,000 BTSCC on average (**Table 1**).

The significant increase ($p < 0.001$) in milk BTSCC during the training period can be explained by the weather season. The trainings were done during summer time (warmer and wetter season), which has favorable climatic conditions for microbial growth (17, 18). Together with the animals being more exposed to mastitis pathogens and the evidence that heat stress can negatively affect their immune system, there will be an increase in BTSCC because of their reduced capability to respond to intramammary infections (19).

It seems that there is a correlation between heat stress and decreased immunity in dairy animals. Thompson et al. (20) showed that heat stress in the dry period negatively affected the immune response later in lactation when cows were submitted to a *Staphylococcus* challenge; the heat-stressed cows had lower

TABLE 1 | Average somatic cell (SCC; ×1,000/mL of milk) and bacterial counts (cfu/mL of milk) measured from bulk tank milk (BTM) samples collected throughout the training period.

Weeks	BTM samples											
	SCC			Total coliforms			Non-agalactiae *Streptococcus*			*Staphylococcus* sp.		
	Farm[a]			Farm			Farm			Farm		
	A	B	C	A	B	C	A	B	C	A	B	C
1	138	224	179	.	100	.	.	1,091	128	.	150	350
2	133	239	169	425	0	525	600	500	24,500	100	30	24,000
3	155	262	199	15	.	0	220	.	2,525	1,050	.	2,000
4	141	252	197	100	.	24,000	322	.	497	347	.	1,850
5	168	271	211	1,050	.	0	1,450	.	8,825	1,400	.	13,500
6	170	281	220	0	.	50	4,300	.	11,500	400	.	86,000
7	147	276	217	5	.	0	2,175	.	2,500	435	.	6,425
8	168	304	206	0	.	215	925	.	1,000	800	.	150
9	173	278	216	15	100	100	105	185	10,350	350	200	0
10	166	279	214	0	200	0	35	1,350	1,500	115	200	450

[a]*Weeks had significant effect ($p < 0.05$) on milk SCC only.*
"." indicates missing data.

neutrophils counts and SCC in milk than thermoneutral cows. They also found that heat-stressed cows during the dry period had higher incidence of mastitis later in ensuing lactation. In 2015, the warmest day was June 9 (93°F), and the hottest month was July (average daily high temperature of 81°F), as reported by the National Weather Service records (21). The significant increase in BTSCC is within the range expected for the summer season and probably has no relation with the training sessions.

Identification of pathogens in milk is considered as the definitive diagnosis of intramammary infections in dairy herds, and it is important for disease prevention and control. BTM analysis is a good tool to identify the weak management areas and procedures that are probably being practiced. *Streptococcus agalactiae*, mainly transmitted from cow-to-cow (with contaminated udder wash cloths or teat cups), was not described in any of the farms during the training period (data not shown).

Microbiological identification in the BTM samples is described in **Table 1**. *Staphylococcus* sp. are often found on cow skin and are transferred to milk *via* poor udder milking preparation. Decreasing counts during training may be associated with increased knowledge of milking preparation, hygiene, and routine consistency. *Staphylococcus* sp. counts varied by farm ($p < 0.05$). Farm C showing the highest counts but, as observed in **Table 1**, we did not detect a significant effect of the period ($p = 0.54$). Follow-up sampling during subsequent months would have been necessary to determine a significant effect of the training on other milk quality traits.

In **Table 1**, the results for *non-agalactiae Streptococcus* normally present in teat skin and environment showed no statistical trend for any farm or training period. The bulk tank sampling period only during training may not be appropriate to determine the effectiveness of cow preparation and to evaluate changes made in milking protocols prior to milking. Additionally, the coliform counts did not differ significantly by farm. However, lower counts were observed during the last 4 weeks of training (Farm A and C; $p < 0.05$; **Table 1**). The number of coliforms in BTM is almost entirely related to skin contamination at the time of milking and to the degree of bedding contamination with coliform bacteria (22). These results may indicate better hygiene practices as indicated in positive feedback from farm A owner and manager.

In the "Dairy Tool Box Talks" lack of motivation to learn or improve working environment were offset by interactive, engaging, and pictographic training. Other incentives were "social time" with employees. (e.g., handouts, pizza, gifts) and a training certificate of completion.

Nearly 70% of the workers were in attendance at the last session and actively contributed showing their appreciation and interest in almost all the topics presented. They showed special interest for mastitis and milk quality, milking procedures, hygiene in general, zoonosis awareness, cultural differences, ergonomics, overall U.S. law and sanctions, and cow handling. The employees also called the program informative and dynamic, expressing desires to continue the learning process with topics not covered, such as farm management, artificial insemination, and calving practices. Nearly 85% of the employees agreed that sessions helped them being more confident in doing their job, and 76% considered the length of the program as adequate. On the other hand, 95% expressed a desire for more owner and managers directly participating during the talks. Remarkably, 95% believed that receiving a training certificate was valuable for their current job or future jobs.

Owners, managers, and herdsmen's comments included noticeable changes in employee behavior, improved working relations, positive attitude at the workplace, better working performance, and more awareness on hygiene issues. The sessions were highly effective because they were given in the workers' native language. An overall improvement in milker's attitudes about the milking procedures was also observed. Other notable observations were that employees moved cows better by being patient, calm, and consistent with them. These changes could increase employee's productivity, reduce the costly on-the-job accidents caused by uninformed workers, and improve the retention rate. The "Dairy Tool Box Talks" is an excellent example of how employee training programs and manager and/or owner involvement can lead to more effective communication and improved work performance within the dairy.

CLOSING REMARKS

The feedback of the "Dairy Tool Box Talks" program provided a general sense of employee satisfaction, great learning achievement, and enthusiasm for the sessions. The social challenge in large modern dairy farms is employees' understanding, awareness, and motivation. Cultural considerations, especially training in Spanish, were key for the success of this program.

The training program was viewed successful by the owners and managers. The topics covered were appropriate and helpful with a format that met the needs of each farm's schedule and milking shift changes. When owners and managers participated during a session, more positive employee responses were noted about the topic.

In the future, the "Dairy Tool Box Talks" trainings will be offered in the original 10 week period or a shorten version. Further trainings involving other farms should be planned in order to evaluate the potential impact of this pilot program and its contribution to long-term sustainability within the dairy sector. A follow-up survey to evaluate the employees learning achievement along with periodic BTM samples is also needed.

AUTHOR CONTRIBUTIONS

Each author made substantial contributions to conception and design of this proposal as well as the acquisition and interpretation of data.

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REVIEW
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A Guide to the Design of Occupational Safety and Health Training for Immigrant, Latino/a Dairy Workers

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Industrialized dairy production in the U.S. relies on an immigrant, primarily Latino/a, workforce to meet greater production demands. Given the high rates of injuries and illnesses on U.S. dairies, there is pressing need to develop culturally appropriate training to promote safe practices among immigrant, Latino/a dairy workers. To date, there have been few published research articles or guidelines specific to developing effective occupational safety and health (OSH) training for immigrant, Latino/a workers in the dairy industry. Literature relevant to safety training for immigrant workers in agriculture and other high-risk industries (e.g., construction) was examined to identify promising approaches. The aim of this paper is to provide a practical guide for researchers and practitioners involved in the design and implementation of effective OSH training programs for immigrant, Latino/a workers in the dairy industry. The search was restricted to peer-reviewed academic journals and guidelines published between 1980 and 2015 by universities or extension programs, written in English, and related to health and safety training among immigrant, Latino/a workers within agriculture and other high-risk industries. Relevant recommendations regarding effective training transfer were also included from literature in the field of industrial–organizational psychology. A total of 97 articles were identified, of which 65 met the inclusion criteria and made a unique and significant contribution. The review revealed a number of promising strategies for how to effectively tailor health and safety training for immigrant, Latino/a workers in the dairy industry grouped under five main themes: (1) understanding and involving workers; (2) training content and materials; (3) training methods; (4) maximizing worker engagement; and (5) program evaluation. The identification of best practices in the design and implementation of training programs for immigrant, Latino/a workers within agriculture and other high-risk industries can inform the development of more effective and sustainable health and safety training for immigrant, Latino/a dairy workers in the U.S. and other countries.

Keywords: dairy industry, immigrant Latino/a workers, occupational safety and health, health education, safety training

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INTRODUCTION

Compared to other industries, workers in the U.S. dairy industry experience higher rates of work-related illnesses and injuries (1–3). Aspects of dairy work that pose a threat to worker health and safety include operating hazardous machinery, performing dangerous livestock handling tasks, exposure to hazardous substances (e.g., manure, dirty water, dust, various chemicals), environments prone to slips, trips, and falls, and tasks requiring high repetition, awkward postures, and inadequate rest (1, 4). The U.S. dairy industry relies on an immigrant, primarily Latino/a workforce to meet the demands of operating large-herd, industrialized farms (5, 6). Although detailed surveillance data documenting the patterns of occupational injuries, illnesses, and fatalities in the dairy industry are lacking (7), high rates of injuries and illnesses among immigrant workers have been reported (8–10). Given the direct and indirect expenditures associated with workplace injuries and illnesses, including the high costs of workers' compensation, and the social burden of injuries and illnesses on individual workers, their families, and communities, it is essential to ensure provision of optimally designed occupational safety and health (OSH) training for immigrant, Latino/a workers in the dairy industry (9).

There are few federal regulations surrounding OSH training in the dairy industry. The Agricultural Exceptionalism law, which was put in place as a way to protect family farms but continues to shield large-scale industrial agriculture, deems the dairy industry exempt from many of the standards enforced in other industries (11). Due to this lack of regulation, OSH training on U.S. dairies is scant, varied in terms of content and scope, and not applied universally (12–16). Román-Muñiz et al. (13) interviewed 72 workers representing 15 dairies to better understand current training available on Colorado dairies. Nearly three quarters reported receiving task-related training (73.6%), while just over half (56.9%) reported receiving safety training upon being hired. Of great concern, nearly one-fifth (19.4%) claimed to have received no job or safety training at all. Focus group studies with dairy workers in Wisconsin (14) as well as in Colorado and South Dakota (15) also found insufficient OSH training. Sorge et al. (16) surveyed dairy producers to assess current cattle handling training on Minnesota dairy farms, of which approximately 25% reported providing no training to new employees. The most commonly mentioned barriers to training were time limitations (39.4%) and language barriers (26%).

It seems that even when OSH training is provided on dairies, it may not have the intended impact on health and safety outcomes. For instance, the previously mentioned study by Román-Muñiz et al. (13) did not find a significant relationship between safety training and injury outcomes. This is not surprising given that training on U.S. dairy farms is often not adequately tailored for an immigrant, Latino/a workforce (10, 12). The majority of immigrant, Latino/a dairy workers have limited formal education, speak little or no English, and have low levels of literacy (17). Many also have limited or no previous dairy experience or foundational training on OSH and, as a result, fail to recognize the hazards in their work (7, 18–20). Immigrant workers also experience a number of unique psychosocial stressors, such as social isolation (21, 22), poverty (22–25), discrimination (15, 22), and lack of employment security (26), that need to be understood and taken into account when developing OSH programs. Such workers may be more likely to take risks at work and less likely to use safety equipment, follow safety procedures, and voice concerns about unsafe conditions (10).

There are few published research articles and guidelines specific to developing effective OSH training programs for immigrant, Latino/a workers in the dairy industry (27). To address this gap, literature relevant to safety training for immigrant, Latino/a workers in agriculture and other high-risk industries was reviewed to identify current practices, promising approaches, and recommendations. The aim of this review is to provide a practical guide for researchers and practitioners involved in the design and implementation of OSH training programs for immigrant, Latino/a workers in the dairy industry. Future interventions will likely be more successful if they build on lessons from the past (28).

MATERIALS AND METHODS

The literature search was restricted to peer-reviewed academic journal articles and guidelines that were (1) published between 1980 and 2015; (2) by universities or extension programs; (3) written in English; and (4) related to OSH training among foreign-born immigrant, Latino/a workers within agriculture and other high-risk industries. The following databases were used for the search: Academic Search Premier, Agricola, CAB Abstracts, ERIC, MEDLINE, PsycInfo, and Web of Science. Three categories of search terms were used as follows: (1) OSH training (i.e., training, safety training, safety education, industrial safety); (2) immigrant, Latino/a workers (i.e., immigrant, migrant, Hispanic, Latino/a, Spanish-speaking worker, foreign born); and (3) agriculture and other high-risk industries (i.e., dairy, farming, agriculture, construction, forestry, mining, transportation, high-risk industry). A Boolean search of article abstracts included terms from each category in an additive manner (AND) while including terms within each category in a disjunctive manner (OR).

The above criteria were used to select only abstracts showing a relationship to the topic. First, article abstracts were reviewed to assess applicability. If abstracts included insufficient information to determine relevance, then the full text was reviewed. Reference lists from published papers were also screened to identify additional articles not identified in the initial search. Articles were excluded from further analysis if they (a) did not concern immigrant, Latino/a workers and (b) did not provide suggestions or insights related to OSH training. A summary of recommendations to promote training transfer, defined as the transfer of the knowledge and skills learned in training to the work context, were also included from literature in the field of industrial–organizational psychology.

RESULTS

The review uncovered a number of articles related to designing OSH training for immigrant, Latino/a dairy workers. A total of 97 articles were identified, of which 65 are cited in Sections

"Results" and/or "Discussion". Thirty-two of the identified articles were not included either because they did not meet the inclusion criteria upon review or because they did not make a unique and significant contribution beyond those already cited. Articles cited include literature reviews, intervention studies, survey studies, qualitative studies, scale validation studies, and case studies, as well as publications regarding training transfer best practices. Additional articles are cited to provide relevant context and background information. The literature on OSH recommendations was categorized by five main themes: understanding and involving workers, training content and materials, training methods, maximizing worker engagement, and program evaluation. Following is a description of each theme with relevant recommended strategies. See **Table 1** for a summary of recommended strategies.

Understand and Involve Workers

Among immigrant, Latino/a workers, there is great variation in terms of country of origin, level of education and acculturation, language and literacy skills, current and past socioeconomic status, legal status, and experiences of racism and discrimination (29). Even workers who come from the same country can have vastly different life experiences and occupational backgrounds (7) and varying exposure to OSH hazards and safety training (30). In order to develop effective and appropriately tailored OSH training, it is essential to understand the diverse realities of immigrant, Latino/a workers. Formative research and community-based participatory (CBP) methods are two promising approaches for understanding workers through active involvement.

Formative Research

Formative research aims to understand the knowledge attitudes, opinions, skills, beliefs, and needs of the target population in relation to the health issues of interest and can take many forms, including literature reviews, health assessments, observations, interviews, and focus group discussions (31, 32). Formative research should include both dairy management and the workers themselves to identify key issues, ensure relevance, and gain buy-in through both bottom–up and top–down approaches (7, 33). If OSH programing is developed based on the expressed needs and concerns of dairy management and the workers themselves, they will feel their voice has been heard and may be more inclined to actively engage in it (or in the case of dairy management, promote engagement in it) as a result (34).

CBP Methods

CBP methods have been suggested as a way to continue to engage managers and workers as key decision makers throughout the entire OSH program design, implementation, and dissemination process (35). The aim of taking a CBP approach is to bring

TABLE 1 | Summary of recommended approaches and example of key strategies for each theme.

Theme	Recommended approaches	Example key strategies (citation/s)
Understand and involve workers	Formative research Community-based participatory methods	• Include dairy management and workers in the process (7, 28, 33) • Consider the goals/strengths of all stakeholders (35) • Provide multiple avenues for participation (35)
Training content and materials	Be comprehensive	• Train all workers on OSH across all areas of the dairy (7, 41) • Focus on the how *and* why of safety procedures (42, 43) • Provide resources for where to get help with OSH (46) and non-work (22) issues
	Be language and literacy appropriate	• Provide materials in workers' native language/s and keep materials at a low reading level (56) • Use realistic and common symbols, objects, and settings (51, 52) • Use various strategies [e.g., a decentering translation approach (49), field testing (58), cognitive interviewing (53), collaboration with ESL and literacy professionals (54), provision of learning aids (55, 56)] to ensure comprehension
	Embrace cultural diversity	• Understand and incorporate workers' core cultural beliefs (49, 60), avoid stereotypes, and remain sensitive to varying levels of acculturation (49) • Include familiar culture phenomenon, same race/ethnicity role models, and deliver materials in a way workers are accustomed to receiving information (29, 58)
	Acknowledge workers' realities	• Ensure materials reflect day-to-day realities of the workplace (15) and the rapid pace of change in the dairy industry (27)
Training methods	Use a variety of formats and media Promote active participation	• Use multiple formats/media to accommodate low literacy and different learning preferences (7, 65) • Reinforce training content through quizzes and games rather than written formats (44) • Tailor methods to cultural attitudes toward learning and other cultural factors (44, 74)
	Empower workers	• Allow workers to develop their own OSH goals and action plans (28) • Foster leadership skills for organizing and taking action (44)
	Enlist peers as trainers Promote training transfer	• Adopt the *Promotoras de Salud* model (79–82) • Foster motivation (43, 85, 93) and efficacy to apply training content (84, 86) • Highlight situational cues within and outside of the workplace (78) • Provide additional learning and practice opportunities after training (84)
Maximize engagement		• Consult workers regarding training logistics (75, 89) • Encourage dairy management to foster a strong culture of OSH through their words and actions (7) • Treat OSH training as an ongoing process rather than a one-time event (73)
Program evaluation		• Evaluate the impact of the program as well as the process • Utilize quantitative, qualitative (99, 100), and longitudinal methods when possible

together members from the target group and program developers in order to "establish trust, share power, foster co-learning, enhance strengths and resources, build capacity, and examine and address community-identified needs and health problems" (36) (p. 14). There are many ways to adopt a participatory approach. For instance, workers can assist in the development of training materials and company documents and policies related to OSH, the latter of which often include legal and technical jargon that would confuse even the most educated and experienced readers (37). CBP methods facilitate increased access to and trust with community members and result in programs that are more culturally and educationally appropriate, sustainable, and replicable in other communities (35). CBP approaches capitalize on the valuable insights and collective strengths of the target group while also developing their capacity to advocate for and achieve change (35). Arcury et al. (35) reviewed five CBP programs aiming to prevent pesticide exposure among migrant and seasonal farmworkers to identify common elements of successful CBP projects. They emphasized the importance of taking the time to build and maintain relationships with and understand the goals and strengths of all stakeholder groups concerned with promoting OSH (e.g., workers, family members, farmers, general community residents, advocacy groups, healthcare providers), being flexible and creative, and providing multiple avenues for participation so different stakeholders can get involved to their own ability/comfort levels. See Quandt et al. (38) for an example of a CBP approach to develop a pesticide safety program with Mexican farmworkers in North Carolina.

Training Content and Materials

In addition to being based on sound health communication principles [e.g., see Rowan (39) for risk communication guidelines], OSH training content and materials must be tailored to the unique needs of immigrant, Latino/a dairy workers. Overall, content and materials should be comprehensive and appropriately tailored in terms of language and literacy, cultural diversity, and workplace realities.

Be Comprehensive

Many immigrant workers have limited or no previous dairy experience (14, 15, 40), and therefore OSH programs should be comprehensive in terms of covering all potential hazards (7). Overall, it should not be assumed that workers have even basic OSH knowledge. In addition to safe animal handling, operation of hazardous machinery, and prevention of environmental risks (e.g., heat-related illnesses), dairy workers should also be trained on body mechanics and ergonomics to prevent musculoskeletal disorders common in industrialized dairy (41). OSH training should cover both the how and why of protective measures and all workers should be trained equally, regardless of previous experience, as task and safety procedures vary across dairies (42, 43). Workers should be trained in safety for all areas of the dairy, especially when there is a tendency for job rotation. Trainings should also educate workers about health insurance and workers compensation (14, 15), as well as their rights and responsibilities under OSHA, and provide information and resources on where to get help in addressing OSH problems (44, 45). Additionally, trainings should include information pertaining to employer responsibilities and how workers can go about pursuing grievances when these responsibilities are not fulfilled (46).

Finally, OSH programs should also be holistic in the sense of acknowledging non-work-related challenges faced by immigrant, Latino/a workers. For instance, financial strain, separation from family, and poor work–life balance could lead to stress and family dysfunction, which in turn could affect productivity and safety at work (21). Workers should be provided with information regarding affordable and accessible community resources and services available to help cope with some of these non-work issues (22).

Be Language and Literacy Appropriate

With few exceptions [e.g., Ref. (33, 47)], language and literacy appropriate OSH trainings for immigrant, Latino/a workers are rare. This poses a serious problem: if workers cannot understand the content and materials, they will be minimally effective in promoting OSH. In terms of language, training materials should be provided in Spanish and English (and/or another language native to workers) to accommodate workers who may feel more comfortable with one language than the other (48). When translating materials, an approach known as *decentering*, which prioritizes conceptual clarity over literal translation, has been recommended [see Brunette (49) for a more detailed description]. Care should be taken to use tildes and accents as appropriate, as they influence the meaning of many Spanish words (48). Immigrant, Latino/a farmworkers have been found to have an average of 6 years of education; thus, it is generally recommended to keep materials at a low reading level (50). Materials including realistic and vivid symbols with well-known objects and settings and the use of traffic light colors to communicate risk level have been suggested for use with Latino/a farmworkers (51, 52).

To ensure that materials are at the appropriate level, they should be field tested with members of the target audience who are not able to fluently read or write in either language (44). Cognitive interviewing, in which members of the target group are given the training materials and asked to articulate their understanding of the information in order to determine if the intended messages are being communicated, may be a particularly useful approach in this context (53). Health and safety educators can also collaborate with ESL and literacy professionals to ensure that content is at the right level (54). To ensure comprehension of common dairy industry terms, McGlothlin et al. (55) recommended providing workers with a pictorial glossary with a description of basic and advanced terminology to refer to during training as well as after training is complete. Similarly, Opatik and Novak (56) recommended provision of a pocket size pronunciation guide.

Embrace Cultural Diversity

Simple translation of OSH materials with subtitles in the necessary language(s) and at the appropriate level is not sufficient (49, 57). On a basic level, training content should incorporate familiar cultural phenomenon. For instance, materials should include same race/ethnicity role models and be packaged in a way that is similar to how workers are accustomed to receiving information in their home countries (58). At the same time, it is important to avoid cultural stereotypes and remain sensitive to varying levels of acculturation. Members from the target population should review materials to confirm cultural relevance (49).

Beyond aligning training with familiar cultural phenomenon and imagery, concerted effort should be made to understand and incorporate the core cultural beliefs of the workers (especially those that may affect OSH) into training materials (49). Latinos/as tend to share a common set of values that are different from those found in mainstream American culture, such as higher levels of in-group collectivism, greater acceptance of hierarchical power structures, and stronger adherence to traditional gender roles (59, 60). For instance, *familism* (i.e., a strong attachment to nuclear and extended family) is a central value among Latinos/as that may influence OSH behaviors (60). Training content and materials should emphasize the family-related implications of not adhering to OSH policies and procedures. Immigrant workers also have diverse cultural beliefs related to health behaviors, which need to be understood and integrated into OSH training (61, 62). Training should sensitively emphasize the implications of adhering to potentially risky traditional practices and beliefs (63). See Sanders-Smith (48) for a review of cultural issues that impact the Latino/a workforce.

Acknowledge Workplace Realities

It is essential that OSH training is reflective of workers' day-to-day realities (15). When safety information is viewed as meaningful, valuable, and relevant to everyday experiences, it may enhance motivation to learn and aid with memorization and recollection processes (63). One way to ensure OSH training reflects workplace realities is to integrate it with task training as much as possible (13). Whether delivered separately or in conjunction with task training, careful attention should be made to acknowledge what is feasible or realistic for the workers. For instance, merely informing workers of safety policies and procedures does not acknowledge the fear of negative consequences workers may have if they act on or report hazardous situations (7). It is also important to regularly update and adapt OSH trainings to coincide with the rapid pace of change in organizational practices in the dairy industry, such as changes in globalization, migration patterns, and the economy (27).

Training Methods

In addition to training content, the methods by which OSH training programs are delivered must also be carefully tailored to meet the unique needs of immigrant, Latino/a dairy workers. Overall, native Spanish-speaking trainers are suggested over English-speaking trainers with translators given the difficulty in ensuring accurate translation (64). Ideally, trainers should be bilingual *and* bicultural so that they can aid in promoting comprehension of OSH concepts while adjusting for relevant cultural influences (58). A few basic principles to follow are to use a variety of formats and media, promote active participation, empower workers, enlist peers as trainers, and promote training transfer.

Use a Variety of Formats and Media

It is likely that some workers may not have developed the skills to learn through formal education and, therefore, may have limited ability to learn new concepts through traditional pedagogical approaches. A variety of formats (e.g., audio-visual, face to face, verbal communication, hands-on) and media (e.g., flipcharts, videos, comic books, cartoons, *fotonovelas*, targeted brochures) should be utilized to accommodate low literacy levels and different learning preferences (7). See Reinhardt et al. (65) for an example of a training using various formats and media in the context of dairy OSH. One creative approach that has proven to effectively increase health-related knowledge among immigrant, Latino/a farmworker populations is the use of theatrical presentations to disseminate health information [e.g., Ref. (66, 67)]. For instance, Holmes et al. (41) found a combined a Spanish language *fotonovela* play, a live demonstration and practice session, and educational pamphlets effective in promoting correct lifting techniques among predominantly female, Latino/a fruit warehouse workers.

Computer-based instruction may be considered as a more cost efficient training modality compared to in-person training. Anger et al. (68, 69) found support for using computer-based instruction in promoting OSH knowledge and behavioral outcomes among Latino/a workers with limited formal education. Evia (70) proposed a participatory approach to design culturally tailored computer-based OSH training for Latino/a construction workers. Mobile phone and internet-based interventions may also be promising modes of OSH training, but may be more effective with younger working populations (71).

Promote Active Participation

There is a large literature base suggesting that trainings based on active participation are more effective than lecture-based trainings (72). There are numerous ways to promote active engagement in trainings, such as group problem solving, hazard mapping, hands-on demonstrations and simulations, role-playing activities, photo voice, and other art-based approaches (see O'Connor et al. (44) for a more detailed list of approaches and Román-Muñiz et al. (73) for examples of hands-on demonstrations in the dairy context). In reviewing training content, verbal quizzes and games should be used instead of written formats to reinforce training messages and to invite discussion or questions (44). Trainees should also be provided with regular feedback so that they can evaluate their progress and learn from their mistakes (44).

It is also important to consider cultural attitudes toward learning and adjust training methods accordingly. For instance, Latino/a workers may perceive expressing dissenting opinions or asking questions as disrespectful, so instructors may need to make extra efforts to encourage active participation (74). For example, it may be necessary to break trainees into small groups to make them feel comfortable discussing issues and sharing their experiences (44). Cultural variation in gender dynamics should also be considered. For instance, trainees may feel more comfortable sharing if grouped by gender (44). Given the strong value placed on family within Latino/a culture, it may also be beneficial to determine ways to involve family members in the learning process. For instance, workers can be sent home with information to share or an activity to work on with their family.

Empower Workers

OSH training will be minimally effective if workers do not feel empowered to implement the lessons learned. There are a number of ways in which trainings can be tailored to empower workers to stay healthy and safe. At the individual level, OSH training activities should empower workers to identify and analyze OSH issues and develop their own solutions and action plans (44). Hurley and Lebbon (9) suggested that workers regularly meet with managers to set safety-related goals, which would also serve to further strengthen worker–manager relations. Assertiveness training may also be beneficial in terms of helping dairy workers to overcome fears of speaking up regarding OSH issues and concerns (75). However, Shrestha and Menzel (76) piloted an assertiveness training as part of a fall prevention training targeting Latino/a construction workers and found that a low percentage of workers identified the training as useful. They attributed this finding to the possibility that workers may view speaking up about safety issues as a threat to their job security, which is often prioritized over safety. At the collective level, training should present safety as a shared responsibility, encourage workers to discuss risk and protective factors with one another, and promote leadership skills for organizing and taking action in terms of advocating for provision of personal protective equipment and remediation of hazards in the work environment (44, 77, 78).

Enlist Peers as Trainers

Immigrant, Latino/a dairy workers may be more likely to learn about OSH from their coworkers than from formal training programs. Román-Muñiz et al. (13) found that training provided by coworkers had a protective effect against work-related injuries, but this effect was not found when provided by dairy managers. They speculated that coworkers may be better able to deliver safety information in an informal and culturally acceptable manner, compared to managers who may have inadequate Spanish language skills and/or a limited comprehension of the cultural factors that influence effective communication (p. 23).

The *Promotoras de Salud* model is an approach that relies on trained lay Latino/a community members to deliver health messages and has been found to be effective in changing OSH attitudes and behaviors of immigrant, Latino/a workers in high-risk jobs [e.g., Ref. (79–82)]. Bush et al. (81) piloted a *promotoras* program with forest workers and found increased knowledge and awareness of OSH risks and resources. They highlighted the importance of providing non-literacy-based outreach and training tools and leadership development opportunities for *promotoras* and engaging *promotoras* in community outreach to connect with workers in comfortable environments (e.g., homes, community festivals, churches). It is also important that *promotoras* be frequently praised; educated regarding local, state, and national events affecting immigrant workers; supported in troubleshooting personal, community, and work-related obstacles; and provided with an honorarium to make the investment of their time worthwhile and foster a sense of accomplishment (82). The value of adopting participatory approaches, both in terms of training methods and project planning has been emphasized in order to promote effectiveness, commitment, and leadership skills among peer trainers (83).

Despite the many benefits of peer trainers, some workers may prefer to receive training from an expert because: (1) an expert might be viewed as more knowledgeable and therefore be taken more seriously and (2) a trained peer might leave causing a sudden loss of benefit from their knowledge (38). Therefore, it could be beneficial to use a combination of peer and expert trainers.

Promote Training Transfer

Training transfer, a construct from the field of industrial–organizational psychology, is the extent to which the knowledge and skills learned in training are transferred to the job (84). In order to promote the transfer of training, first trainees must feel motivated to learn and have efficacy to apply training content to the workplace (84). Latino/a workers' perceptions of work as essential to life and pain as an inevitable part of work (61) and beliefs that animal-related injuries are not preventable (15) may cause them to be less motivated to engage in the preventive behaviors promoted in OSH programing. Special efforts may be needed to supersede these beliefs and help workers understand the efficacy and value of prevention. The goal should be to help workers develop motivation, confidence, and critical thinking skills to apply OSH training content to protect themselves from the myriad hazards they face in their work. Some programs offer incentives, such as a completion certificates, to motivate training transfer [e.g., Ref. (43, 75)]. As previously suggested, internal motivation can be fostered by personalizing OSH training content to the day-to-day realities faced by workers and managers to ensure that they perceive it as relevant and useful (85). Self-efficacy can be promoted through behavioral modeling (including both positive and negative examples of desired behaviors) and providing opportunities for trainees to practice using new knowledge/skills (86). Role-playing exercises and other types of simulations can be beneficial in terms of promoting active learning and providing opportunities to practice (84). It is also important to help trainees recognize the challenges they may face in implementing the new knowledge and skills and brainstorm strategies to overcome them through error management techniques (87).

Training should be conducted in an environment that closely resembles the workplace to make for a more natural transition from the training context to the work context (84). Kraiger et al. (84, 88) recommended varying training scenarios to help trainees develop the skills they will need to handle issues across multiple conditions that can occur on the job. Training should also highlight situational cues within and outside of the workplace that will help trainees remember to engage in OSH behaviors (78). For instance, Quandt et al. (78) encouraged trainees to lay a mat outside the door of their home as a visual reminder that work boots should be removed before entering to keep their children and other family members safe from harmful exposures. To promote sustained training transfer, it is also important for trainings to foster supervisor and peer support to engage in OSH behaviors and provide additional learning opportunities after training (e.g., through refresher training and after action reviews) (84).

Maximize Worker Engagement in OSH Programing

If workers are not engaged in OSH initiatives, they are not likely to benefit from them. In order to maximize engagement, it is important to acknowledge that workers may not view safety as their number one priority and build OSH content into trainings on other topics that workers view as higher priorities (which can be identified through formative research) (44). Workers should be consulted regarding the ideal duration and scheduling of OSH trainings (75, 89). A high level of engagement can also be promoted by collaborating with community organizations that already have a well-established relationship with the immigrant, Latino/a community [e.g., Ref. (33, 90)]. To ensure continued engagement, it is also important that OSH training be treated as an ongoing process that all workers, regardless of tenure, are encouraged to participate in, rather than a one-time event (73).

Another key approach to enhancing worker engagement is for dairy owners/managers to foster a strong culture of OSH throughout the dairy. Due to the frequency of their exposure to OSH hazards, dairy owners/managers may deny susceptibility to risk or be skeptical of safety measures and give workers the impression that the health and safety of the cows is prioritized over that of the workers (7). Programs are needed to educate dairy owners/managers about the realities concerning various risks inherent in dairy work, the impact of poor OSH on productivity and the bottom line (7), and how to foster an atmosphere of trust in which workers feel their safety is a priority. Dairy owners and managers should be actively involved in trainings, which will in turn enhance perceived safety culture and inspire workers to transfer the OSH knowledge and skills learned to the workplace (7, 73). It may be beneficial to start by assessing safety climate, a measure of safety culture, to identify areas of strength and opportunities for improvement. Measuring changes in safety climate across time can also be used to assess the impact of OSH interventions [see Jorgensen et al. (91) and Flynn (92) for more on assessing safety climate among workers from different backgrounds].

Program Evaluation

OSH programs in the agricultural sector have historically lacked rigorous program evaluation (12, 93). This deficiency greatly limits the potential of such programs to contribute to the evidence base of what does and does not work in terms of protecting and promoting worker health. To ensure the optimization of OSH training for immigrant, Latino/a dairy workers, program evaluation is critical. In addition to providing evidence of programmatic worth, evaluation can be used to identify strengths and weaknesses, examine the extent to which goals are being met, and supply information that can be used to improve program outcomes (94–97). Evaluations should assess whether OSH programs are having the intended impact on worker attitudes and behaviors as well as incidents of work-related injuries and illnesses (i.e., impact evaluation) and collect the views of dairy workers and management related to program strengths and weaknesses and suggestions for improvement (i.e., process evaluation). Some have suggested conducting process evaluation during the implementation phase so feedback can be used to make improvements before the end of the program [e.g., Ref. (98)]. It may be necessary to provide bilingual staff members to assist non-literate participants in completing evaluation materials verbally (41, 75).

Whether conducting an impact or process evaluation, both quantitative and qualitative approaches (i.e., mixed methods) should be utilized to provide a richer view of the knowledge level, attitudes, and practices of low literacy workers (99). Ahonen et al. (100) used a participatory, mixed methods approach to evaluate the design, delivery, reactions, participant learning, application of skills, dissemination, strengths and weakness, and return on investment of an OSH training with Spanish-speaking immigrant construction workers. Longitudinal methods are beneficial for assessing longer term program impacts but may be challenging due to high rates of turnover in the dairy industry. See Vela-Acosta et al. (33) for another example of a mixed methods evaluation approach used with Latino/a farmworkers and DeRoo and Rautiainien (12) and O'Connor et al. (44) for further recommendations related to program evaluation.

DISCUSSION

Despite increasing reliance on immigrant, Latino/a workers within the dairy industry, few studies to date have focused on OSH training for this high-risk group. In order to fill this gap, the goal of this review was to summarize current strategies embraced by OSH training for immigrant, Latino/a workers from agriculture and other high-risk industries in order to provide a practical guide for researchers and practitioners involved in the design and implementation of effective OSH training programs for immigrant, Latino/a workers in the dairy industry. Overall, whether programs are developed from the ground up or borrowed from elsewhere, it is essential that training materials and methods be based on a deep understanding the characteristics and realities of the immigrant worker (58). Strategies must also be adopted to maximize worker engagement and, in turn, program impact on OSH outcomes.

Of concern, this review revealed that many OSH programs targeting immigrant, Latino/a workers in high-risk industries fail to embrace established cultural models and systematic program and process evaluation. These deficiencies could result in the implementation or replication of programs that are based more on practitioners' perceptions and intuitions about how to tailor interventions for Latino/a workers than on empirically tested theories. Also of concern is the fact that many programs are one-time events; yet, high rates of turnover and mobility among immigrant dairy workers demand an ongoing approach to training (7).

Seguridad en las Lecherías (17) is a recently developed program to promote OSH among immigrant, Latino/a dairy workers in Wisconsin that adopts many of the suggested guidelines. *Seguridad en las Lecherías* is a theory-based program utilizing the *promotoras* model for the first time within the dairy context. The program was developed based on formative research conducted to understand the perspectives and needs of dairy workers and producers. It was designed to be engaging, appropriate for workers with limited formal education and low literacy, and easy to replicate. It was conducted in partnership with various stakeholders (e.g., the Professional Dairy Producers of WI, the Mexican Consulate of St. Paul) who have extant knowledge of and experience with immigrant, Latino/a dairy workers. See Tovar-Aguilar et al. (101) for an example of another program that utilized many of the best practices outlined in this review to promote eye safety among Latino/a citrus harvest workers.

Limitations and Future Research

There are many important directions for future research related to OSH programing for immigrant, Latino/a dairy workers. First, there is a great need for additional studies to better understand the prevalence and nature of occupational injuries and illnesses among this working population, which can guide the prioritization of OSH programs. In order to acquire accurate epidemiologic data, efforts are needed to improve reporting of work-related injuries, illnesses, and near misses (7). Although the present review identified a number of promising strategies, systematic meta-analyses are also needed to assess the relative effectiveness of intervention approaches that incorporate the specific training needs of the Latino/a workforce.

It is important to keep in mind that training programs are just one component of OSH for immigrant, Latino/a dairy workers. Training programs are limited in that they only focus on the individual worker, rather than addressing the root cause of injuries and exposures (102). Hagevoort et al. (103) have advocated for a macro approach to OSH programing, inclusive of the workers, the work environment, as well as cultural, social, and economic factors external to the work context. Higher level policy changes and their proper enforcement are needed to standardize OSH training for the dairy industry and address the challenging life circumstances of immigrant, Latino/a workers (104, 105). It is also important to promote access to and utilization of health services (106) and ameliorate physical and psychosocial stressors among immigrant, Latino/a workers, which have been associated with decreased cognitive function and mental health-related outcomes (107). OSH initiatives focused on engineering and administrative controls in addition to those focused on individual behavior change are also essential in reducing workplace hazards (108).

Another major difficulty related to promoting OSH among immigrant, Latino/a dairy workers lies in the considerable communication barriers between workers and non-Latino/a dairy owners and managers (89). In addition to OSH training, ESL and SSL classes should be provided to improve communication and comprehension of OSH materials (109). Programs targeting dairy management are also needed to promote safety leadership, engagement in OSH programing, cultural awareness, and skills in building positive and trusting relationships with immigrant, Latino/a workers (110). See Viveros-Guzmán and Gertler (111) for additional suggestions regarding improving communications between immigrant farmworkers and their employers.

CONCLUSION

The U.S. dairy industry and its workforce have undergone dramatic transformations in recent decades (14). OSH training programs in the dairy industry must take into account changing workforce demographics and the realities of a global immigrant workforce. Training programs that adapt to the needs of their specific workforce will have the greatest impact and effectiveness. Given the high rates of occupational injuries and illnesses in the dairy industry and the increasing reliance on an immigrant, primarily Latino/a workforce, efforts to protect and promote health and safety must be sensitive to the unique attitudes, understandings, and behaviors of immigrant, Latino/a workers. As stated by Liebman et al. (17), "it is incumbent upon the industry to address the risks associated with bringing a naïve workforce into one of the most dangerous areas (large-animal agriculture) of one of the most dangerous industries (agriculture) in the country" (p. 81). This review marks an initial step in identifying current practices and promising approaches in the design and implementation of OSH training programs for immigrant, Latino/a workers within agriculture and other high-risk industries to inform the development of more effective and sustainable OSH training for immigrant, Latino/a workers in the dairy industry. It is our hope that the programs reviewed provide a significant foundation which researchers and practitioners can challenge, test, and build upon.

AUTHOR CONTRIBUTIONS

All authors (LM, JR, LS, and IR-M) have (1) contributed substantially to the conception or design of the work and/or the acquisition, analysis, or interpretation of the data for the work, (2) participated in drafting the work or revising it critically for important intellectual content, (3) approved the final version to be published, and (4) agreed 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. LM and IR-M contributed to the design of the work, analysis and interpretation of the data, and the drafting and revising of the manuscript. LS and JR contributed to the design of the work and the drafting and revising of the manuscript.

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Occupational Health and Safety of Finnish Dairy Farmers Using Automatic Milking Systems

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Introduction: Conventional pipeline and parlor milking expose dairy farmers and workers to adverse health outcomes. In recent years, automatic milking systems (AMS) have gained much popularity in Finland, but the changes in working conditions when changing to AMS are not well known. The aim of this study was to investigate the occupational health and safety risks in using AMS, compared to conventional milking systems (CMS).

Methods: An anonymous online survey was sent to each Finnish dairy farm with an AMS in 2014. Only those dairy farmers with prior work experience in CMS were included in the final analysis consisting of frequency distributions and descriptive statistics.

Results: We received 228 usable responses (131 male and 97 female; 25.2% response rate). The majority of the participants found that AMS had brought flexibility to the organization of farm work, and it had increased leisure time, quality of life, productivity of dairy work, and the attractiveness of dairy farming among the younger generation. In addition, AMS reduced the perceived physical strain on the musculoskeletal system as well as the risk of occupational injuries and diseases, compared to CMS. However, working in close proximity to the cattle, particularly training of heifers to use the AMS, was regarded as a high-risk work task. In addition, the daily cleaning of the AMS and manual handling of rejected milk were regarded as physically demanding. The majority of the participants stated that mental stress caused by the monotonous, repetitive, paced, and hurried work had declined after changing to AMS. However, many indicated increased mental stress because of the demanding management of the AMS. Nightly alarms caused by the AMS, lack of adequately skilled hired labor or farm relief workers, and the 24/7 standby for the AMS were issues that also caused mental stress.

Conclusion: Based on this study, AMS may have significant potential in the prevention of adverse health outcomes in milking of dairy cows. In addition, AMS may improve the productivity of dairy work and sustainability of dairy production. However, certain characteristics of the AMS require further attention with regard to occupational health and safety risks.

Keywords: agriculture, automatic, dairy, farmer, health, milking, occupational, safety

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INTRODUCTION

Occupational injuries and diseases, and other disabling health conditions, are frequent in western agriculture (1, 2). Livestock farmers and workers, particularly those working on dairy farms, are at risk of various adverse health outcomes (3, 4). In addition to acute injuries caused by cattle and the working environment, chronic musculoskeletal conditions result from physical exertion and paced, repetitive, and strenuous working motions and postures in conventional pipeline and parlor milking (4, 5). Respiratory diseases are also frequent among dairy farmers (6).

Investing in and modernizing dairy farm production may have positive effects on the work quality and quantity as well as work safety of dairy farmers (7, 8). Lindahl et al. (4) and Douphrate et al. (5) have reviewed safety practices and interventional efforts to prevent injuries and musculoskeletal disorders in conventional milking systems (CMS).

Studies suggest that automatic (robotic/voluntary) milking systems (AMS) may be of notable help in creating healthier and more attractive working places for future dairy farmers (5, 7). In recent years, AMS have gained much popularity in Finland, other Nordic countries, and elsewhere (9, 10).

The review of Jacobs and Siegford (11) gives a comprehensive description of the technological principles of the AMS. Furthermore, Rodenburg (12) summarizes the current understanding of a robotic barn design, which to some extent, differs from a free-stall (loose housing) barn with a conventional milking parlor.

In the AMS, cows are enticed by concentrate feed to enter the milking stall, where the milking robot cleans the teats, attaches the teat cups, milks the udder on a quarter-basis, detaches the teat cups, and sprays the teats with disinfectant. With regard to work tasks in milking, the role of the dairy worker changes to a great extent from a manual laborer to a system administrator.

The majority of the studies related to AMS focus on the health and welfare of dairy cows, quality and quantity of milk, robotic barn design including cow traffic, and the economy of milk production (11–18). These aspects are important for the improvement of the dairy farmers' expertise and the profitability of the dairy production. In addition, they may indirectly improve the well-being of dairy farmers and workers as well.

Changing to AMS typically reduces the daily labor requirement in milking and may improve the quality of life through providing more flexibility in work schedules (19–22). According to a survey charting socioeconomic aspects of AMS, it may improve the physical health of dairy farmers, compared to CMS (21). However, there is only limited information on the occupational safety issues regarding the dairy farmers and workers using AMS.

Our survey study had two primary aims. First, we aimed to characterize the key features of the Finnish AMS farms. Second, we aimed to investigate the occupational health and safety risks in using AMS among Finnish dairy farmers compared to their prior experiences in CMS. This information can be used to generate recommendations for the prevention of adverse health outcomes among present and future dairy farmers and workers in Finland and elsewhere.

MATERIALS AND METHODS

Study Setting

Finnish agriculture is based on privately owned family farms. The self-employed farming population includes farmers, spouses, and other salaried family members. They compose over 90% while hired non-family employees compose less than 10% of the permanent workforce on Finnish farms (23). In addition, municipal and private farm relief workers contribute significantly to farm work, especially on dairy farms. In Finland, the statutory farm relief worker services enable farmers with the defined number of livestock (e.g., at least 6 dairy cows, 24 suckler cows, or 90 fattening pigs) to take an annual vacation (26 days in 2016) free of charge while the relief worker takes care of the animal husbandry (24).

In 2014, there were 52,775 farms including 8,370 dairy farms in Finland (25). More than two-thirds (69%) of the dairy farms had a tie-stall (stanchion) barn with a pipeline milking system, and the rest (31%) had a free-stall barn with a milking parlor or an AMS (26). The average herd size was 35 dairy cows; greater in free-stall barns than tie-stall barns, 55 vs. 24 dairy cows, respectively (26).

There were three AMS brands available on the market in Finland at the time of the study. Depending on the AMS brand, one milking robot may operate either one or two milking stalls. According to annually updated sales statistics (9), 904 Finnish dairy farms had AMS with a total of 1,259 milking stalls at the end of 2014. The average number of milking stalls per AMS farm was 1.4. In 2014, the Finnish AMS farms represented about 11% of all dairy farms, but being larger than average, they produced about 25% of the total milk production (9).

Data Collection

We conducted an online survey of all Finnish dairy farms with an AMS in 2014. Our survey included 22 multiple-choice and open-ended questions charting the key features of the Finnish AMS farms (listed below).

- *Sociodemographic data*: gender and age of the participants (owner-operator).
- *Animal husbandry data*: the number and type of persons contributing to daily animal husbandry, the usage of farm relief workers, workplace orientation, and job guidance of farm relief workers and hired labor, the number of lactating and non-lactating (dry) dairy cows, the presence of rubber flooring in the dairy barn, and prior work experience in CMS (pipeline, parlor, or both).
- *Automatic milking data*: year when AMS was introduced, the number of milking robots, the number of milking stalls, annual milk production, handling method for rejected milk such as colostrum (first milk after calving), type of cow traffic, the number of fetched dairy cows daily, the presence of an operator pit and a closable holding area next to the milking stall(s), training of heifers to use the AMS, incidence of nightly alarms caused by the AMS, and satisfaction with the AMS.

Occupational health and safety risks in AMS vs. CMS were investigated using seven sets of Likert-scale questions with instructions and definitions. The following issues were charted on a five-point scale (*reduces significantly*, *reduces to some extent*, *no significant difference*, *increases to some extent*, and *increases significantly*) augmented with an opt-out choice (*can't tell*).

- Physical strain in using AMS caused by work that is dynamic (mobile), static, or both – in general and in various body regions.
- Mental stress in general and caused by the specific nature of work in using AMS.
- Risk of occupational injuries caused by various work tasks in using AMS augmented with an open-ended choice.
- Occupational and other work-related diseases caused by different exposures in using AMS.
- Other factors related to AMS.

In addition, the following issues were charted on a three-point scale (*not at all*, *some*, and *a lot*).

- Physical strain in various work tasks related to AMS augmented with an open-ended choice.
- Mental stress in various issues related to AMS augmented with an open-ended choice.

Our survey was pre-tested by two farmers with an AMS, and some of the questions were edited based on their comments. The Finnish AMS importers forwarded our e-mail cover letter with a link to the survey to their customers, one owner-operator from each AMS farm. One reminder e-mail was sent to all AMS farms.

Our study aimed to compare occupational health and safety risks between AMS and CMS. Hence, only those dairy farmers with at least 1 month of prior work experience in CMS were included in the final analysis. We did not compare specific characteristics (e.g., model, age, or accessories) of the AMS brands or the differences between the brands in our study.

The research team (authors) asserts that this study was performed in accordance with relevant research ethic guidelines based on the Declaration of Helsinki (27). The research team had no access to identifiable information on the study participants. The email invitation to participate stated the purpose of the study and that the online survey was voluntary and anonymous. Informed consent was not used. The companies that emailed the survey invitation to their customers had no access to the responses received by the research team. All responses were stored on a secured server. Ethics approval was not applied as Finnish ethical guidelines do not request it concerning survey studies, which are not interfering with the physical and mental integrity of the study subjects.

Statistical Methods

The data analysis included examining the means, minimums, and maximums of the continuous variables and categorizing them for further analysis. The frequencies of categorical variables were tabulated, and some variables were reclassified. The Pearson correlation coefficient was calculated for selected variables. The two-tailed chi-square test was used for comparing response proportions of categorical variables including gender, age, the number of persons contributing to daily animal husbandry, the number of automatic milking stalls, and the year of installing the AMS. Only statistically significant differences were reported ($p < 0.05$). The statistical analyses were conducted using SPSS Statistics Version 22 (IBM Corp., Armonk, NY, USA).

RESULTS

Characteristics of Farmers and Farms

A total of 228 dairy farmers (131 male and 97 female), one owner-operator per farm, gave usable responses to our survey. The final response rate was 25.2%. Three farmers with no prior work experience in CMS were excluded. Approximately 30% of the responses were obtained after the reminder.

The mean age of the participants was 44 years of age (44 for males and 45 for females). Prior work experience in both conventional pipeline milking and parlor milking was common among the participants (54.8%). Others had work experience in either pipeline milking (35.5%) or parlor milking (9.7%).

The animal husbandry workforce included full-time and part-time owner-operators and hired labor. The majority of the farms (89.9%) had 2–4 persons contributing to daily animal husbandry (range 1–10 per farm), and about half (46.1%) had one or more full-time or part-time hired dairy workers. In addition, 95.2% had a farm relief worker taking care of the dairy cattle during the participants' annual vacation. Few (1.3%) farms had neither hired labor nor farm relief workers contributing to animal husbandry.

The dairy farms had changed to AMS in 2009 on average (range 2001–2014), and about every tenth farm (12.3%) had installed their AMS in 2014. The responding farms had a total of 316 milking robots operating 321 milking stalls (range 1–5 per farm). The average number of milking stalls per farm was 1.4, and the average number of lactating and non-lactating dairy cows was 82 per farm.

The majority of the farms had one milking stall with 61 dairy cows on average (**Table 1**). To protect the identity of the two largest farms with four and five milking stalls, their production-specific information is not reported. The number of dairy cows per farm was significantly and positively correlated with both the

TABLE 1 | Number of AMS farms, milking stalls, dairy cows, and annual milk production per farm in 2014.

AMS farms (Frequency)	Milking stalls per farm (Frequency)	Dairy cows[a] per farm (Frequency)		Annual milk production per farm (Million liters)	
		Average	Range	Average	Range
155	1	61	25–85	0.568	0.150–0.838
56	2	110	62–150	1.021	0.480–1.546
15	3	160	115–200	1.444	1.000–2.010
2	4–5	–	–	–	–

AMS, automatic milking system.
[a]Includes both lactating and non-lactating (dry) dairy cows.

number of milking stalls ($r = 0.90$, $p < 0.001$) and with the annual milk production per farm ($r = 0.94$, $p < 0.001$).

Occupational Health and Safety Risks in AMS

Physical Strain

The dairy farmers' opinions regarding the perceived physical strain in using AMS, compared to CMS, are shown in **Figure 1**. Nearly all participants (98.2%) found that AMS reduced the physical strain in general. Few found no significant difference, and none found increased physical strain after changing to AMS.

Furthermore, our survey included five questions regarding the perceived physical strain in various body regions. The majority of the participants found reduced physical strain in all body regions after changing to AMS. The reduction was most evident on the knee joints, forearms, and hands as well as the shoulder area and upper arms. Some farmers found no significant difference, and few found increased physical strain especially in lower limbs or in the hip and lower back when using AMS, compared to CMS.

Compared to females, greater proportion of male farmers reported reduction of physical strain on the lower limbs from walking, standing, or both when using AMS (85.5 vs. 63.9%) (chi-square test, $p = 0.018$).

Less than half of the participants (42.5%) had rubber covering on one or more of the following areas inside the barn: feed alleys next to the feed table(s), manure alleys between the free stalls, and holding area next to the automatic milking stall(s). The presence (or absence) of rubber covering was not associated with either physical strain or occupational injury risk in our study.

Dairy farmers were also asked to estimate the physical strain in seven work tasks related to AMS (**Table 2**). Daily handling of rejected milk caused some or a lot of physical strain among 66.2% of the dairy farmers. The rejected milk from the AMS was led to either plastic buckets (volume 20 l) or stainless steel buckets (volume 25–30 l), carried away, and emptied manually every day on 85.5% of the farms. Some farms (12.3%) had a specific milk

TABLE 2 | Perceived physical strain in work tasks related to automatic milking (*N* = 228).

Work task	Perceived physical strain		
	Not at all	Some	A lot
	Frequency (%)[a]	Frequency (%)	Frequency (%)
Daily handling of rejected milk[b]	77 (33.8)	141 (61.8)	10 (4.4)
Daily cleaning of the AMS	131 (57.5)	96 (42.1)	1 (0.4)
Fetching cows to the milking stall	163 (71.5)	64 (28.1)	1 (0.4)
Work with the computer	172 (75.4)	53 (23.2)	3 (1.3)
Manual attachment of the teat cups	188 (82.5)	37 (16.2)	3 (1.3)
Daily tasks in the milk room	194 (85.1)	34 (14.9)	–
General observation of the AMS	206 (90.4)	22 (9.6)	–

[a]Percentages may not horizontally add up to 100.0 due to rounding.
[b]Colostrum milk or milk that contains antibiotic residues, excess blood, or somatic cells.
AMS, automatic milking system.

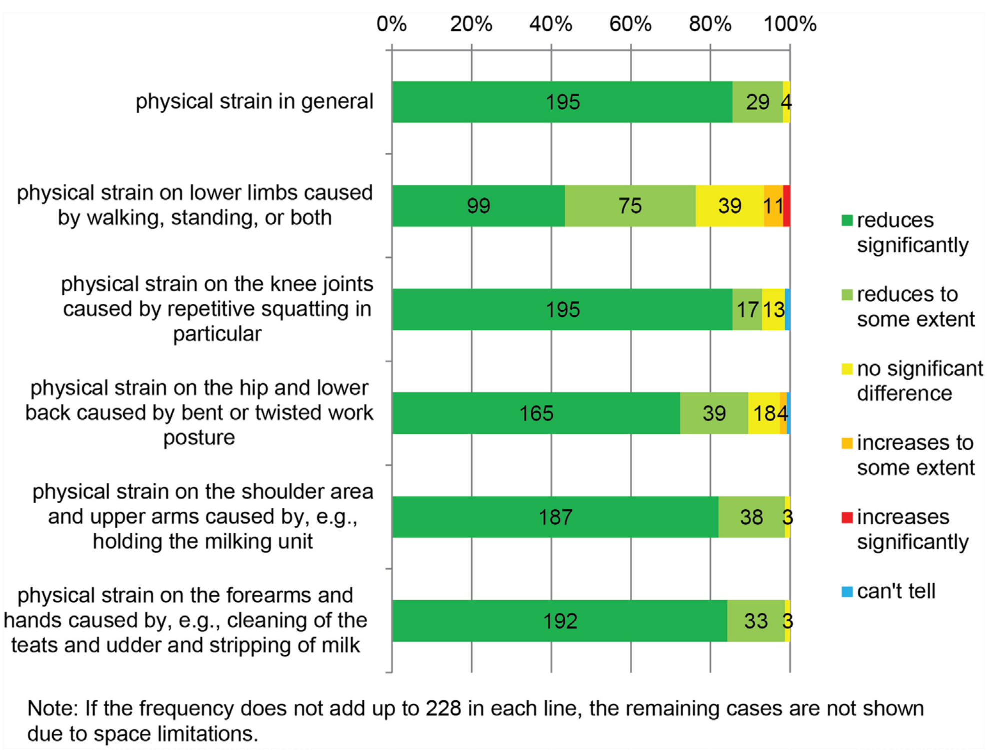


FIGURE 1 | Physical strain in automatic milking compared to conventional milking (*N* = 228).

line for rejected milk leading to a larger container. Few farms had both buckets and a line for rejected milk.

In addition, daily cleaning of the AMS caused physical strain to 42.5% of the participants. This work task includes surface cleaning of the milking robot, teat cups, milk hoses, and automatic milking stall several times per day using a water hose and a brush.

Daily cleaning of the AMS may be conducted either by standing on the same level of the floor where the milking stall is located or by using an operator pit. In our study, 40.8% of the farms had an operator pit located next to the milking stall. The average depth of these pits was about 0.50 m (range 0.20–1.20 m), and 69.9% of the pits were partially surrounded by safety railings. However, the presence or absence of the operator pit was not associated either with physical strain or occupational injury risk in our study.

Management of the daily cow traffic related to AMS was another issue causing physical strain to many farmers (28.5%). The majority of the farms (77.6%) had free cow traffic, and 78.0% of them had a closable holding area next to the milking stall. Guided cow traffic, where a selection gate guides dairy cows with milking permission to the enclosed holding area, was found on 22.4% of the farms.

Most farmers (75.5%) with one automatic milking stall had to fetch fewer than five individual dairy cows daily. Many (23.2%) had to fetch 5–10 cows and some (1.3%) more than 10 cows each day. The average number of cows fetched daily was higher on farms with two or three stalls. Male farmers reported more often that fetching cows to the milking stall caused them physical strain (34.4 vs. 20.6%) (chi-square test, $p = 0.023$).

In addition to the work tasks listed in **Table 2**, training heifers to use the AMS, manual handling of the detergent and disinfectant containers, and repair and maintenance of the AMS were named as tasks causing physical strain.

Mental Stress

Participants' opinions regarding the perceived mental stress after changing to AMS are shown in **Figure 2**. Approximately half (47.8%) found that AMS reduced their mental stress in general. No significant difference in mental stress was reported by 19.7%, and 31.6% stated that their mental stress had increased.

Four questions addressed perceived mental stress caused by the nature of work using AMS. Mental stress from work demands in AMS (vs. CMS) varied among the participants. However, the majority found that changing to AMS had reduced monotonous, repetitive, paced, and hurried work in milking.

Compared to their peers with longer experience using AMS, those who had installed their AMS in 2014 stated more often that AMS had reduced their mental stress in general (71.4 vs. 45.5%) (chi-square test, $p = 0.013$). Further questions addressed eleven aspects of mental stress (**Table 3**). The majority (93.4%) mentioned one or more AMS-related issues causing (some or a lot of) mental stress. Three issues in particular emerged in the responses: nightly alarms caused by AMS, trusting farm relief workers and/or hired labor to manage milking with the AMS, and taking care of the 24/7 standby for the AMS.

Nightly AMS alarms caused mental stress to 71.5% of the participants. The majority (87.3%) had none or few nightly alarms per month, and others had nightly alarms at least weekly (11.8%) or almost every day (0.9%).

Trusting the farm relief workers and/or hired labor to manage with the AMS caused mental stress to 67.6% of the farmers. The

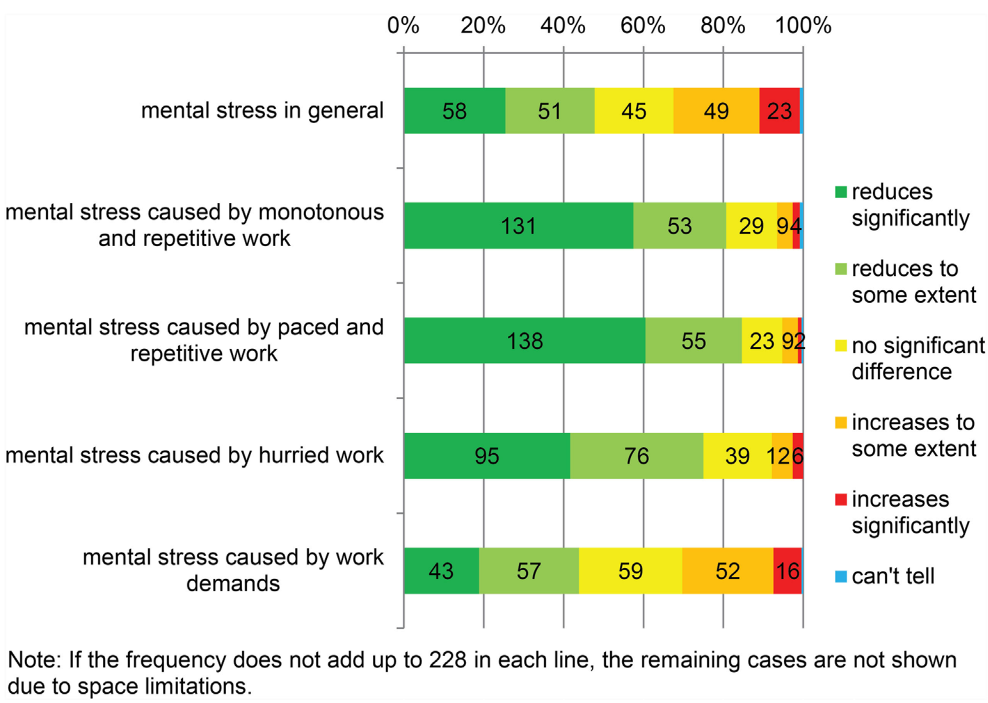


FIGURE 2 | **Mental stress in automatic milking compared to conventional milking ($N = 228$).**

TABLE 3 | Perceived mental stress in issues related to automatic milking ($N = 228$).

Work task	Perceived mental stress		
	Not at all	Some	A lot
	Frequency (%)[a]	Frequency (%)	Frequency (%)
Nightly alarms caused by the AMS	65 (28.5)	117 (51.3)	46 (20.2)
Trusting the farm relief workers, hired labor, or both to manage with the AMS	74 (32.5)	118 (51.8)	36 (15.8)
Taking care of the 24/7 standby for the AMS	110 (48.2)	96 (42.1)	22 (9.6)
Occasionally long work days	131 (57.5)	73 (32.0)	24 (10.5)
Dependency on the timeliness and proficiency of the hired maintenance of the AMS	135 (59.2)	75 (32.9)	18 (7.9)
No clear end for the work day	140 (61.4)	68 (29.8)	20 (8.8)
Trusting the skills of the family members to manage with the AMS	146 (64.0)	75 (32.9)	7 (3.1)
Trusting the operational reliability of the AMS	152 (66.7)	66 (28.9)	10 (4.4)
Alarms caused by the AMS during waking hours	166 (72.8)	60 (26.3)	2 (0.9)
Trusting one's own skills to manage with the AMS	188 (82.5)	37 (16.2)	3 (1.3)
Work with the computer	199 (87.3)	28 (12.3)	1 (0.4)

[a]Percentages may not horizontally add up to 100.0 due to rounding.
AMS, automatic milking system.

majority of them (81.1%) stated that these external workers were given workplace orientation and job guidance orally, and that comprehensive written instructions were available. Other farmers (18.9%) had little or no written instructions.

Several farmers (51.7%) experienced mental stress from the 24/7 standby required for managing the AMS. Dependency on the timeliness and proficiency of hired maintenance of the AMS also caused mental stress, which was reported more commonly by female farmers than males (50.5 vs. 33.6%) (chi-square test, $p = 0.010$). In addition to the issues listed in **Table 3**, power failures and high repair and maintenance costs were mentioned as causing mental stress.

Occupational Injury and Disease Risk

The dairy farmers' opinions on the perceived occupational injury risks in using AMS, compared to CMS, are shown in **Figure 3**. The great majority of them (94.3%) found that AMS reduced injury risk in general. The majority (89.5%) also reported reduced injury risk caused by working in close proximity to the hooves of the dairy cows. However, working in close proximity to the freely moving cows and walking up and down the stairs and on the floor inside the barn divided the participants' views. These issues may relate to both milking and to animal husbandry in general. The minority of the farmers (34.2–46.9%) reported reduced injury risk, whereas about half of the farmers (45.6–54.4%) saw no difference between AMS and CMS. Only few (11.4–15.4%) perceived that the injury risk had increased after changing to AMS. There was a significant gender difference in perceived reduction in injury risk from working in close proximity to the freely moving cows (males 42.7% vs. females 28.9%; chi-square test, $p = 0.033$).

In addition to the issues listed in **Figure 3**, the majority of the participants (73.2%) responded to the open-ended question and described an injury risk related to AMS. Most of them (89.8%) mentioned a task where the worker had to work in close proximity to the cattle. The most commonly mentioned work task (89 responses) was training of heifers and cows to use the AMS. Heifers were not trained to use the AMS before their first calving on 49.1% of the farms, while 31.6% reported training all heifers, and the rest trained some of the heifers.

Other commonly mentioned hazardous work tasks were assisting the AMS and medication and grouping of the cattle. Handling the detergent and disinfectant containers were brought up as potential injury risks as well.

The participants' opinions regarding the perceived occupational disease risk after changing to AMS are shown in **Figure 4**. The majority (87.7%) found that AMS reduced the general exposure to occupational and other work-related diseases. Similarly, the majority found that AMS had reduced specific risks of respiratory diseases, skin diseases, and musculoskeletal symptoms compared to CMS (70.2, 91.7, and 96.1%, respectively). Only few (0.9%) perceived that the risk of occupational diseases had increased after changing to AMS. Several farmers (28.9%) saw no difference in the risk of respiratory diseases in using AMS, compared to CMS.

Other Factors Related to AMS

Several other factors related to AMS vs. CMS are shown in **Figure 5**. The majority of the participants (≥74.1%) found that AMS had brought flexibility to the organization of farm work, and it had increased leisure time, quality of life, productivity of dairy work, and the attractiveness of dairy farming among the younger generation. Furthermore, the majority (≥71.9%) stated that changing to AMS had increased the dairy farmer's own chances as well as the chances of the hired labor and farm relief workers to work healthy and without injuries. However, the perceived possibilities to get adequate sleep after changing to AMS varied among the participants.

The majority of the participants (93.0%) had no intentions to change their current AMS brand or to change from AMS back to CMS. Only few had changed (2.2%) or considered changing (2.2%) their AMS brand, and few (2.6%) considered replacing their AMS with parlor milking. Reasons for the latter were, e.g., that taking care of the 24/7 standby for the AMS had been too arduous for a single farmer, or it would be more flexible to gradually increase the number of dairy cows with a CMS.

DISCUSSION

Automatic Milking Update

Automatic milking systems have been commercially available for almost a quarter century, and they have established a strong

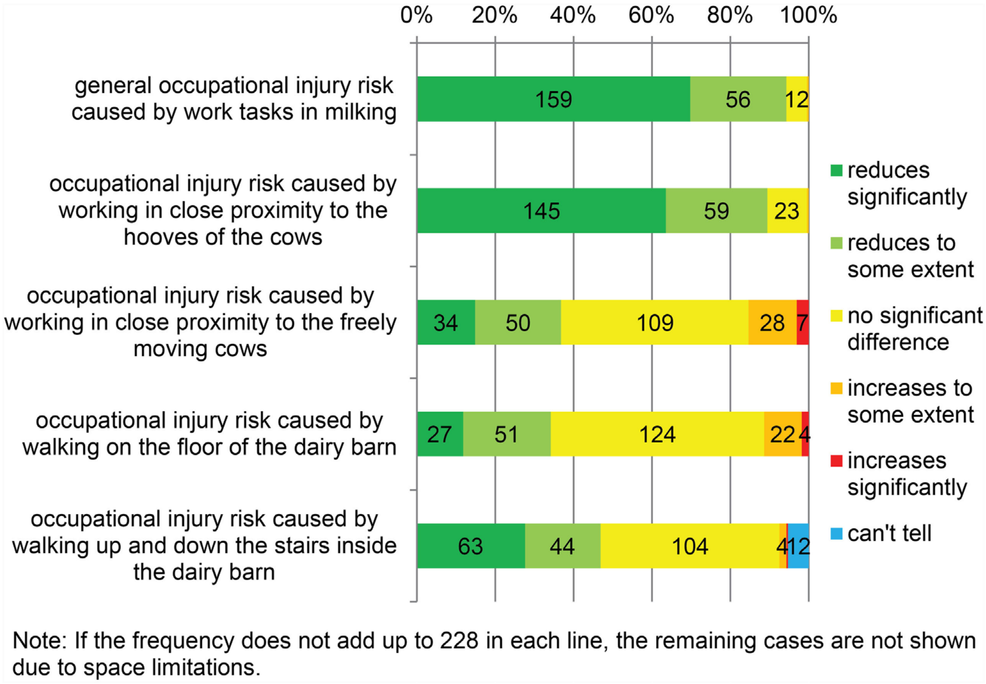


FIGURE 3 | **Occupational injury risk in automatic milking compared to conventional milking (*N* = 228).**

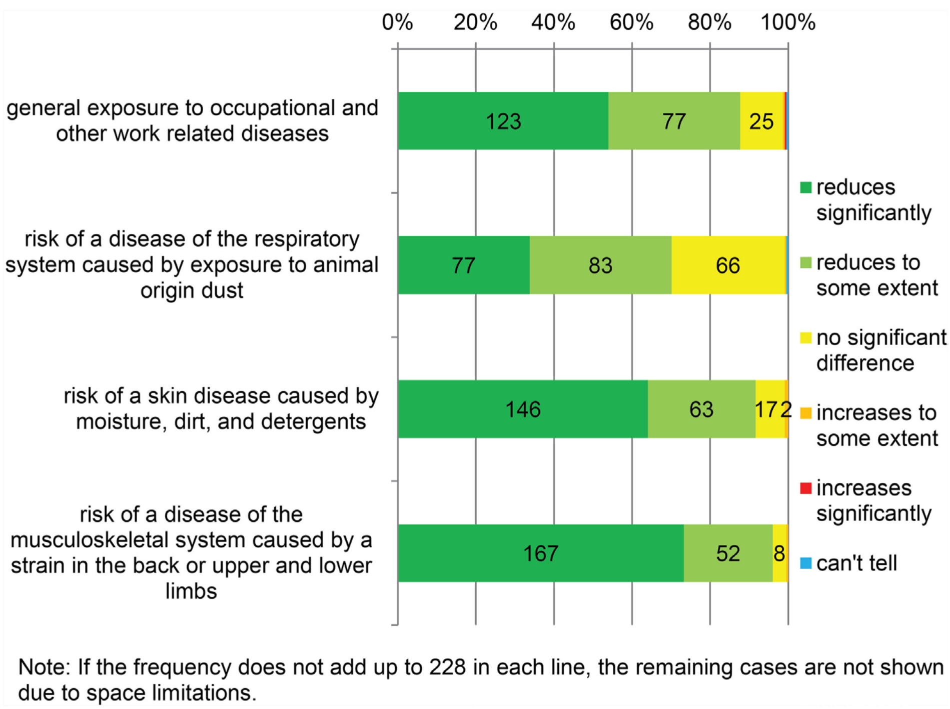
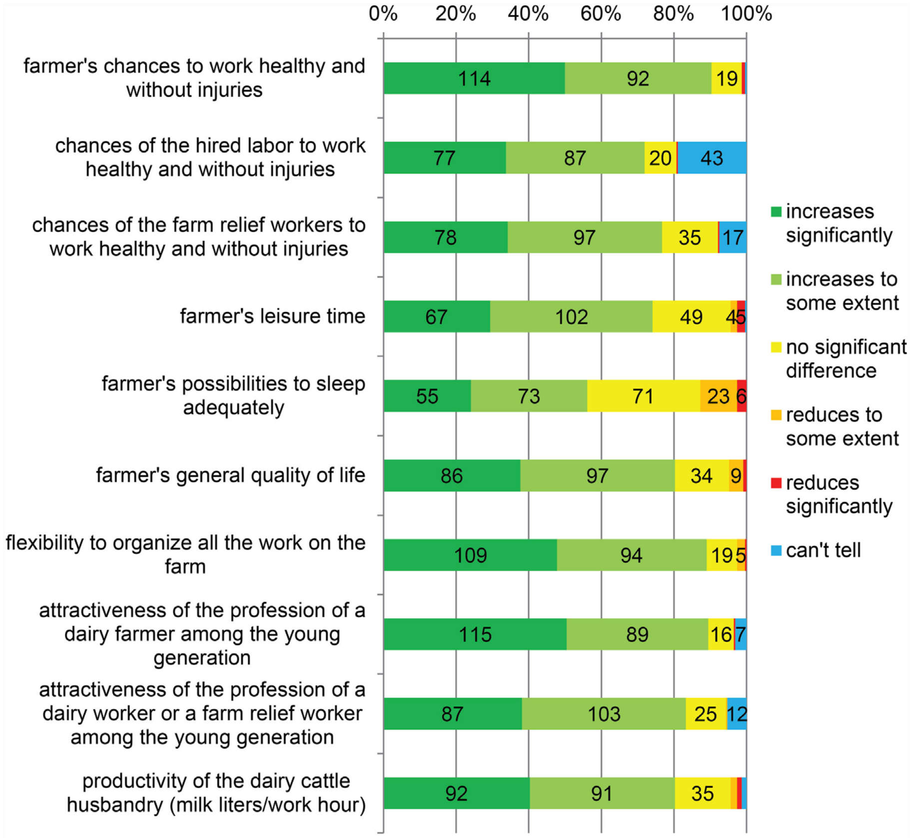


FIGURE 4 | **Occupational and other work-related disease risk in automatic milking compared to conventional milking (*N* = 228).**

position in many countries (9, 10). During the past decade, the total number of AMS farms has increased notably in Finland and other Nordic countries: Sweden, Norway, Denmark, and Iceland (9).

According to annual Nordic dairy statistics, 4,293 Nordic dairy farms had AMS with 6,894 milking stalls in 2014 (9). Outside Europe, AMS has been introduced, e.g., in Canada, USA, New Zealand, and Australia (10, 16). However, there are



Note: If the frequency does not add up to 228 in each line, the remaining cases are not shown due to space limitations.

FIGURE 5 | Other factors in automatic milking compared to conventional milking (*N* = 228).

no current sales statistics available worldwide on the number of AMS.

In the Nordic countries, AMS farms represented about 16% of all dairy farms, 28% of the dairy cows, and 29% of the total milk production in 2014 (9). Nordic AMS farms had 1.6 milking stalls and about 90 dairy cows on average (9). The Danish AMS farms were largest in the Nordic countries with the average of 2.8 milking stalls per farm (9).

Large dairy farms may acquire an AMS with several milking robots and milking stalls (one per about 60 lactating dairy cows), a mixed operation with AMS and conventional milking parlor(s) located in the same or separate dairy barns, or a hybrid milking system where a rotary milking parlor is augmented with either internal or external milking robots. AMS has become an option for a wide size spectrum of dairy farms. However, in North America, large dairy farms still rely primarily on conventional parlor milking, likely due to adequate labor supply and low labor costs.

Many AMS studies have addressed the health and welfare of dairy cows. Among others, Jacobs and Siegford (11) and Hovinen and Pyörälä (13) have reviewed these issues. Proficient knowledge and management skills of dairy farmers with an AMS have been stressed in these and other studies as well (14–16). Even though these issues were mostly out of the scope of our study, we acknowledge their importance for the progress of sustainable dairy production. However, there is only limited information on the occupational health and safety risks in AMS. There is a need for this information because the number of dairy workers involved in AMS is already substantial worldwide and growing.

Occupational Health and Safety in Using AMS

Our anonymous online survey explored changes in working conditions when changing from conventional milking system (CMS) to AMS. This information could be used to generate recommendations for the prevention of adverse health outcomes among the present and future dairy workers in Finland and elsewhere.

Based on our results, changing to AMS reduced the perceived physical strain overall, as well as strain in various body regions. Previous studies have described physical exertion and paced, repetitive, and strenuous working motions and postures, particularly on large dairy farms with CMS (3, 5). AMS may have significant potential in the prevention of chronic musculoskeletal conditions caused by milking.

Some work tasks related to AMS caused physical strain among the participants. Handling rejected milk, daily cleaning of AMS, fetching cows to the milking stall, and training heifers and cows to use the AMS were mentioned. In addition to a specific line for rejected milk used on some AMS farms, we suggest an operator pit and a closable holding area (preferably with rubber flooring) could be of help in reducing physical strain. Soft flooring surface in the barn is beneficial for the cows as well (28).

The optimal depth and other features of an operator pit, which likely differs from that used in conventional parlor milking, should be studied further. We believe that as long as an operator pit is easy to clean, has proper stairs and a non-slippery floor, and is surrounded by safety railings, it may be of help in, e.g., daily cleaning, observation, and assisting the AMS.

Rodenburg (12) recommends free cow traffic with a closable holding area or a specific split entry holding area and rubber flooring in it. This area may be used for the daily fetched cows having problems with mobility or lameness and for training of heifers to use the AMS. In addition to Rodenburg, Lindahl et al. (4) describe methods of safe livestock handling.

Based on our results, mental stress in milking either declined or remained the same after the change to AMS. However, many farmers indicated increased mental stress from the demanding management of the AMS. The majority found that changing to AMS had reduced the monotonous, repetitive, paced, and hurried work in milking. These features of work typically cause both mental stress and physical strain, commonly reported in CMS (29, 30).

Several issues related to AMS caused mental stress. Among others, nightly AMS alarms and taking care of the 24/7 standby for the AMS were mentioned. These distinctive features of AMS are associated with each other: if a serious problem occurs with the AMS, it gives an alarm call to an assigned mobile phone. Hence, the system requires around the clock standby. In addition, many participants experienced mental stress in trusting the farm relief workers, hired labor, or both to manage with the AMS.

We suggest that in addition to workplace orientation and job guidance, vocational and continuing education of all dairy workers participating in AMS work could be of help in reducing mental stress caused by the abovementioned and other issues related to AMS. Developing and offering specific courses with emphasis on the daily management of the AMS would be advisable.

Our results regarding the perceived physical strain and mental stress are consistent with, and augment, earlier findings presented by Mathijs (21), who charted socioeconomic aspects of automatic milking among farmers ($n = 107$) in Belgium, Denmark, Germany, and The Netherlands.

We found that changing to AMS reduced the perceived injury risk in general. This reduction was most evident in the injury risk caused by working in close proximity to the hooves of the dairy cows, which is a typical risk in CMS. According to previous studies (3, 4), dairy cows' kicks, head-butts, and tramples are some of the major causes of occupational injuries on dairy farms.

The majority of our participants mentioned AMS-related work tasks causing injury risks, such as training of heifers and dairy cows to use the AMS, assisting the milking robot, and medication or grouping of the cattle. We suggest that the previously mentioned operator pit and a closable holding area could be of help in reducing the occupational injury risk as well.

Changing to AMS reduced the risk of musculoskeletal, respiratory, and skin diseases. Common respiratory conditions among farmers include allergic rhinitis, allergic asthma, and hypersensitivity pneumonitis caused by organic dust from animals, grain, and hay (3, 31). Common skin diseases among farmers include irritant and allergic contact dermatitis caused by cow dander, moisture, dirt, rubber (e.g., in gloves and boots), disinfectants, and detergents (3, 32).

Male farmers reported reduced physical strain, mental stress, and injury risk more often than female farmers after changing to AMS. Earlier research by Karttunen and Rautiainen (7) described gender division of farm work among Finnish dairy farm couples. Results in the current study are likely affected by the gender division of specific work tasks in animal husbandry. Further studies should address the specific differences by gender in AMS and CMS work.

Other Factors Related to Using AMS

Changing to AMS increased flexibility in the organization of all farm work, the leisure time, and the general quality of life among the majority of the participants. These positive issues may be related to each other; more freedom to shift between work and leisure time likely adds to quality of life. These findings are consistent with previous findings of Mathijs (21), Molfino et al. (22), and Bergman and Rabinowicz (33).

In addition to enhanced physical health of dairy farmers, Mathijs (21) reported improved quality of life after changing to AMS. Molfino et al. (22) conducted labor audits and surveys on Australian AMS farms ($n = 5$) and reported positive impact of the adoption of the AMS on labor and lifestyle. Among others, reduction in physical work and increased flexibility in work schedules were reported (22). Bergman and Rabinowicz (33) addressed reasons for both installing and not installing an AMS on Swedish dairy farms ($n = 734$). Among others, gaining more time for family and friends was regarded as an important reason for installing an AMS (33).

The majority of participants indicated that AMS increased the productivity of dairy work measured by produced milk liters per work hours. However, they had large variation in their number of dairy cows and annual milk production, regardless of the number of automatic milking stalls they had in use. The economic viability of AMS is compromised if the system is not fully utilized, and the productivity of work may also be low as a result. These issues should be examined thoroughly in future studies.

Most participants stated that changing to AMS enabled them as well as their hired labor and farm relief workers to have safer and healthier working conditions. They indicated that changing to AMS increased the attractiveness of dairy farming among the younger generation. Enhanced working conditions (i.e., reduced physical strain, mental stress, injury risk, and disease risk) with AMS may create more attractive workplaces for the current and future dairy workers and improve the sustainability of dairy production.

The majority of the participants had no plans of changing from AMS back to CMS. However, few dissatisfied farmers gave comments that should be paid attention to. First, being on standby around the clock for the AMS may be too tiresome for a single person if there is no substitute worker. Presumably, this issue becomes more of a problem if, e.g., the nightly alarms caused by the AMS are frequent. Second, CMS may be both technically and economically more flexible than AMS regarding the gradual increase in the number of dairy cows.

Strengths and Limitations of the Study

The strengths of this study included covering a large variety of work-related exposures and risks and complete responses to the primary questions due to the data collection method. Reliability of this study was strengthened by including only participants with prior work experience in CMS.

The average number of dairy cows on our study farms was higher than on Finnish dairy farms with a free-stall barn in general; 82 and 55, respectively. With progressing structural change, we believe the farmers in our study population are more likely to continue their production than their peers from smaller farms.

Respondent bias (inability or unwillingness to provide accurate answers) may have affected our results. To reduce this, our survey was pre-tested and edited based on the received remarks, and an opt-out choice was included in all Likert-scale statements. Both five-point and three-point Likert scales were used, depending on the nature of the question. Anchoring descriptions at each level of the Likert scales could have improved the accuracy of the responses, but adding length to questions could have reduced the response rate.

We did not give a definition for mental stress, which can be beneficial or harmful. However, the majority of our study questions regarding mental stress charted negative effects of stress by default.

Classification of the study population based on prior work experience in CMS (pipeline, parlor, or both) could have produced more specific results. Over half of the participants had work experience in both pipeline and parlor milking. It was not possible to differentiate findings between the two types of CMS.

The low response rate (25.2%) was a limitation of our study. The high volume of record keeping and reporting burden in farming may have reduced farmers' interest to participate in our voluntary survey. Our participants possessed 25.5% of all automatic milking stalls active in Finland at the end of 2014. Furthermore, their AMS had on average 1.4 milking stalls, identical to all Finnish AMS farms. These results indicate that our study sample was similar to all Finnish AMS farms with regards to size of the dairy herd and milking stalls per AMS.

It is possible that self-selection of the participants introduced some biases, and it is unknown which way they may have affected the results. On one hand, those with health problems, poor experiences with AMS, or both, may have greater barriers to respond to surveys. On the other hand, those satisfied with their investment in AMS may have been more interested in responding to this kind of survey.

CONCLUSION

Previous studies have indicated that conventional pipeline and parlor milking expose dairy farmers and workers to various adverse health outcomes. Our study investigated the occupational health and safety risks in AMS, compared to CMS.

The results indicate that AMS may have significant potential in the prevention of physical strain and occupational injuries and diseases in milking of dairy cows. In addition, AMS may reduce certain features of work which typically cause mental stress in CMS. Enhanced working conditions and higher productivity of dairy work after changing to AMS may also improve the economic viability and sustainability of dairy production and create more attractive working places for future dairy workers.

However, certain risks in AMS require further attention with regards to occupational health and safety. These include safety in training of heifers to use the AMS, mental stress related to nightly alarms caused by the AMS, ergonomics in the handling of rejected milk, and daily cleaning of the AMS. In addition, expertise of all dairy workers using AMS requires enhancing.

We recommend the inclusion of these results to the vocational and continuing education of the current and future farmers, farm relief workers, and hired workers. In addition to formal education, repeated informing and advising is important. In doing this, positive examples from real life are advisable.

AUTHOR CONTRIBUTIONS

JK and RR conceived and designed the study, collected, analyzed, and interpreted the data, and drafted and wrote the manuscript. CL-K contributed to the interpretation of the data and drafting and writing the manuscript. All authors revised and approved the final manuscript.

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