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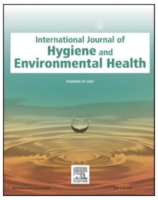

Examination of urinary pesticide concentrations, protective behaviors, and risk perceptions among Latino and Latina farmworkers in Southwestern Idaho

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ABSTRACT

Introduction: Studies have documented high levels of pesticide exposure among men farmworkers; however, few have examined exposures or the experiences of women farmworkers. Data gaps also exist regarding farmworkers' perceived risk and control related to pesticides, information that is critical to develop protective interventions.
Objective: We aimed to compare urinary pesticide biomarker concentrations between Latino and Latina farmworkers and examine associations with occupational characteristics, risk perceptions, perceived control, and protective behaviors.
Methods: We enrolled a convenience sample of 62 farmworkers (30 men and 32 women) during the pesticide spray season from April–July 2022 in southwestern Idaho. Participants were asked to complete two visits within a seven-day period; at each visit, we collected a urine sample and administered a questionnaire assessing demographic and occupational information. Urine samples were composited and analyzed for 17 biomarkers of herbicides and of organophosphate (OP) and pyrethroid insecticides.
Results: Ten pesticide biomarkers (TCPy, MDA, PNP, 3-PBA, 4-F-3-PBA, cis- and trans-DCCA, 2,4-D, Glyphosate, AMPA) were detected in >80% of samples. Men and women had similar urinary biomarker concentrations (p = 0.19–0.94); however, women worked significantly fewer hours than men ($p = 0.01$), wore similar or greater levels of Personal Protective Equipment (PPE), and were slightly more likely to report having experienced an Acute Pesticide Poisoning (26% of women vs. 14% of men; $p = 0.25$). We observed inconsistencies in risk perceptions, perceived control, and protective behaviors among men.
Discussion: Our study is one the first to examine pesticide exposure and risk perceptions among a cohort of farmworkers balanced on gender. Taken with previous findings, our results suggest that factors such as job tasks, biological susceptibility, or access to trainings and protective equipment might uniquely impact women farmworkers' exposure and/or vulnerability to pesticides. Women represent an increasing proportion of the agricultural workforce, and larger studies are needed to disentangle these findings.

1. Introduction

Multiple studies have reported high levels of pesticide exposure among Latinx farmworkers; however, previous examinations have focused predominantly on men (Arcury et al., 2009a, 2009b, 2010a, 2016, 2018a; Krenz et al., 2015; McCauley et al., 2013; Coronado et al., 2004; Habib et al., 2014). Latinx farmworkers are a uniquely vulnerable population who face multiple environmental and occupational threats to their health (Castillo et al., 2021) that may be augmented by

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Abbreviations

APP	Acute Pesticide Poisoning
NAWS	National Agricultural Worker Survey
OP	Organophosphate
PPB	Pesticide Protective Behavior
PPE	Personal Protective Equipment
WPS	Worker Protection Standard

psychosocial stressors such as housing and food insecurity, discrimination, and lack of social support; (Philbin et al., 2018; Winkelman et al., 2013; Torres et al., 2018) cultural and language barriers; (Rao et al., 2004) and limited access to federal aid, legal assistance, and health programs (Castillo et al., 2021; Philbin et al., 2018). Latina farmworkers in particular may face additional stressors that may impact their overall health and wellbeing, including economic discrimination, (Waugh, 2010) sexual harassment, (Waugh, 2010; Bauer et al., 2010; Kim-Godwin et al., 2014; Murphy et al., 2015) inequities in the distribution of childcare and domestic responsibilities, (Curl et al., 2020; Flocks et al., 2012; Quandt et al., 2014; TePoel et al., 2017; Meierotto et al., 2020a; Som Castellano et al., 2022) less secure employment, (Fox et al., 2011) and social isolation (Curl et al., 2020; Flocks et al., 2012; Meierotto et al., 2020b). Women may also be at greater physiological risk to the adverse health impacts of pesticides due to their potential interference with hormonal function, particularly during periods such as pregnancy, lactation, and menopause (Bretveld et al., 2006a, 2006b, 2006c; García, 2003a).

The percentage of women in the agricultural workforce has steadily risen in recent decades, increasing from 21% in 2001 (Carroll et al., 2005) to 34% in 2020 in the United States (Gold et al., 2022). Moreover, studies that have examined occupational pesticide exposure in the US and elsewhere have consistently reported significantly higher rates of acute pesticide poisoning (APP) among women farmworkers compared with their men conterparts (Barrón Cuenca et al., 2020; Zhang et al., 2011; Kasner et al., 2012; Calvert et al., 2008; Lekei et al., 2020). For example, a study examining data from the California Department of Pesticide Regulation and the Sentinel Event Notification System for Occupational Risks (SENSOR)-pesticides program from 1998 to 2007 reported that women farmworkers had an incidence rate of APP that was 2.2 times higher than men farmworkers (Kasner et al., 2012). Few studies have examined pesticide exposure and protective behaviors among women farmworkers, resulting in data gaps regarding potential causes of discrepancies in rates of APP by gender.

In addition to the need for studies directly comparing pesticide concentrations among men and women recruited from the same population, there are knowledge gaps regarding perceived risk perceptions and perceived control to reduce pesticide exposure among Latinx farmworkers, information that is critical to promoting individual and workplace protective behaviors. Risk perceptions are influenced by factors such as race, gender, and immigration status, (Gustafsod, 1998; Adeola, 2007; Chakraborty et al., 2017) and it is possible that men and women farmworkers vary in their perceptions of pesticide risk, which could influence Pesticide Protective Behaviors (PPBs) and ultimately impact pesticide exposure. While some previous studies have documented risk perceptions specifically as they relate to agricultural work among Latinx farmworkers as a whole, (Arcury et al., 2002a, 2006; Cabrera et al., 2009; Walton et al., 2017a) including the impacts of documentation status, (Edelson et al., 2018) pesticide risk perceptions by gender remain inadequately characterized. In the absence of studies assessing farmworkers' own perceptions and experiences as they relate to pesticides, efforts to improve farmworker protection may fall short.

Given the body of literature showing that PPBs, including wearing PPE, are associated with lower urinary pesticide concentrations, (Barrón Cuenca et al., 2020; Walton et al., 2016; Fuhrimann et al., 2020; Levesque et al., 2012; López-Gálvez et al., 2018; Furlong et al., 2015; Salvatore et al., 2008; Quandt et al., 2006; Hernández-Valero et al., 2001; Bradman et al., 2009) it is imperative to understand the risk perceptions of Latinx farmworkers and the barriers they face in adopting behaviors to reduce pesticide exposure, including whether perceived challenges differ by gender. Centering the perspectives of farmworkers is critical in order to develop practices and policies that maximize the benefits of employment in the agricultural workforce while minimizing the potential hazards of occupational pesticide exposure. The aims of this study were to compare urinary pesticide concentrations among men and women Latinx farmworkers, and to examine associations of urinary pesticide concentrations with occupational characteristics, risk perceptions, perceived control, and PPBs.

2. Methods

2.1. Recruitment and enrollment

We worked with multiple community partners to enroll a convenience sample of farmworkers during the pesticide spray season (generally defined as April–July, based on conversations with local agricultural experts such as land grant extension specialists) in south-central Idaho. We aimed to enroll 60 farmworkers who identify as Hispanic/Latina/Latino, including 30 who identify as women and 30 who identify as men.

Individuals were recruited from April 24-July 22, 2022 through collaborations with local health districts, housing authorities, healthcare providers, and community organizations serving farmworkers; mobile health clinics; food box distribution events; Head Start meetings; and snowball sampling. Bilingual (English/Spanish) study staff approached potential participants, briefly described the goals of the study, and administered an eligibility questionnaire to interested individuals. Individuals were eligible if they 1) were 18 years or older, 2) identified as Hispanic/Latino/Latina, 3) spoke English or Spanish, and 4) were currently employed in agriculture and working with food crops. During the eligibility questionnaire, participants were asked to self-identify as a man, woman, or other/non-binary. If the potential participant was not yet working in crop production but planned to during the study period, study staff collected their phone number and name to contact them at a future date. If the individual was eligible and interested in participating, study staff read the informed consent process with the individual in their preferred language (English or Spanish) either at that time or during the first study visit. We communicated with participants to identify times and locations that were convenient for study visits that also maximized confidentiality and anonymity. All materials containing identifiable participant information were stored in a locked cabinet and password-protected database in a locked lab at Boise State University. All study procedures were approved by the Boise State University Institutional Review Board.

2.2. Data collection

All participants were asked to complete two study visits within seven days, each of which included the administration of a questionnaire (one detailed and one brief, as described below) and the collection of a urine sample. All data collection occurred in the participant's preferred language (English or Spanish). We recruited evenly by gender throughout the study to minimize the influence of potential confounding by time.

At the first study visit, study staff administered a questionnaire assessing demographic information, occupational history, crops participants worked with and job tasks within the previous three days, current and typical PPE use, risk behaviors and PPBs during and after work (e.g., washing hands with soap and water while working, removing work clothes before entering the home, showering after work), perceived control to minimize the potential harmful impacts of pesticides, and perceived risk of pesticides. Following the completion of the first study visit, study staff scheduled a second visit at the time and location of the participant's choosing within seven days of the first visit. At the second study visit, study stuff administered a short questionnaire assessing recent occupational pesticide exposure, including crops and job tasks within the previous three days, whether pesticides were applied at any of the farms where they worked within the previous three days, and use of PPE while working in the previous three days.

Questions on perceived risk and control were largely adapted from a previously published questionnaire from a study examining migrant farmworkers' perceptions of pesticide risk in Pennsylvania (Edelson et al., 2018). These questions were predominantly informed by the Health Belief Model (HBM), which aims to explain and predict health-related behaviors based upon six tenets, including risk susceptibility, risk severity, benefits to action and barriers to action, self-efficacy, cues to action, and demographics (Edelson et al., 2018). The questionnaires were originally written in English and translated by three bilingual (English/Spanish) study staff. We piloted the questionnaires with former farmworkers in English and Spanish and edited the questionnaires for clarity and brevity and updated the translation based on suggestions from pilot participants. The questionnaire from the first study visit is available in English in the Supplementary Material.

2.3. *Urine collection*

At each of the two study visits, participants were provided a 100 mL polypropylene cup and asked to provide at least 30 mL of urine. Study staff labeled the urine cup with the participant's anonymous ID and stored the urine sample in a sealable plastic bag in a transport cooler with ice packs. Immediately following the completion of that day's data collection, study staff transported the samples to the Curl Agricultural Health Lab (CAHL) at Boise State University. Urine samples were stored in the CAHL refrigerator at 4 °C for no more than 24 h. The timing of collection, arrival at the lab, and specific gravity analysis (as described below) were tracked on a chain of custody form.

Trained lab members analyzed the samples for specific gravity, color, and clarity, and aliquoted samples into separate 5-mL cryovials. Study staff created four regular vials for each sample, as well as four composite vials intended to represent each participant's mean exposure from the two samples without introducing a freeze-thaw cycle. For the regular vials, study staff aliquoted 4.0 mL of each participant's sample into four separate 5-mL cryovials and stored these samples at −80 °C. For the composite samples, we aliquoted 2.0 mL of each participant's first sample into four separate 5-mL cryovials and stored the samples at −80 °C. After collecting the participant's second sample, we removed the composite cryovials from the freezer, aliquoted another 2.0 mL on top of the participant's first sample, and returned the cryovials to the freezer. One vial of each participant's composite urine sample as shipped on dry ice overnight to Center de Toxicologie du Québec (CTQ), Institut national de santé publique du québec (INSPQ) for analysis in August 2022. All vials were labeled with the participant's unique and anonymous ID number and lab staff were blinded to the participant's identity or demographic information (e.g., gender).

2.4. *Urine analysis*

Determination of 17 pesticide biomarkers distributed over two analytical methods was performed by the Laboratory of Center de Toxicologie du Québec (CTQ), INSPQ (Quebec City, Quebec, Canada) (Larose et al., 2023). The first analytical method included 13 pesticide biomarkers in the multi-pesticide residue panel, including OP insecticides (p-nitrotoluene [PNP], 3,5,6-trichloro-2-pyridionol [TCPY], 2-[(dimethylphosphorothioyl)sulfanyl] succinic acid [MDA], 2-isopropyl-6-methyl-4-pyrimidinol [IMPY], and 2-diethylamino-6-methyl pyrimidin-4-ol [DEAMPY]; pyrethroid insecticides (3-phenoxybenzoic acid [3-PBA], 4-fluoro-3-phenoxybenzoic acid [4-F-3-PBA], cis-3-(2,2-dichlorovinyl)-2,2-dimethylcyclopropane carboxylic acid [cis-DCCA], trans-3-(2,2-dichlorovinyl)-2,2-dimethylcylcopropane [trans-DCCA], and cis-3-(2,2-dibromovinyl)-2,2-dimethylcyclopropane carboxylic acid [cis-DBCA]); and herbicides (2,4-dichlorophenoxyacetic acid [2,4-D], 2,4,5-trichlorophenoxyacetic acid [2,4,5-T], and 3,6-dichloro-2--methoxybenzoic acid) [Dicamba].

Urine samples (250 μL) were enriched with labeled internal standards. The urinary metabolites were then hydrolyzed with β-glucuronidase enzyme solution (6300 units/mL) in a pH 5.0 acetate buffer and incubated overnight at 37 °C. Thereafter, the samples were extracted by a solid phase extraction (SPE) on Strata-X cartridges (30 mg/3 mL; Phenomenex, Torrance, CA, USA) and eluted with a 1% acetic acid methanol solution. The extracts were evaporated to dryness and reconstituted in 100 μL of acetonitrile: methanol: water solution (14:31:55, v:v:v).

The samples were then analyzed by Ultra Performance Liquid Chromatography (UPLC I-Class, Waters Acquity, Waters; Milford, MA, USA) with a tandem mass spectrometer (MS/MS; AB Sciex 7500 system; Concord, Ontario, Canada) in the Multiple Reaction Monitoring (MRM) mode with an electrospray ion source switching in the positive/negative mode. Chromatographic separation was achieved on an Acquity Premier BEH C18 100 mm × 2.1 mm; 1.7 μm analytical column with VanGuard Fit (Waters; Milford, MA, USA). The limits of detection (LODs) for the pesticide analytes were between 0.004 and 0.1 μg/L (Table S1). The intra-day precision ranged from 2.5 to 8.5% and the inter-day precision ranged from 3.2 to 14% depending on the analytes. The internal reference materials used to control the quality of the analyses were in house quality controls (low, medium, high QCs) prepared by the CTQ/INSPQ from spiked urines.

Four other biomarkers, including Glyphosate and Glufosinate and their respective metabolites (aminomethylphosphonic acid [AMPA]) and 3-(methylphosphinico)propionic acid [3-MPPA]) were also measured in urine samples using a second analytical method, as described previously (Bienvenu et al., 2021). Briefly, the urine samples (100 μL) were enriched with label internal standards. Thereafter, the samples were derivatized with a pentafluorobenzyl bromide solution before to be extracted with methyl tert-butyl ether (MTBE) from the aqueous matrix using a liquid-liquid extraction. The extracts were evaporated to dryness and reconstituted with 1000 μL of 2 mM ammonium acetate in 40% acetonitrile. The extracts were then analyzed by Ultra Performance Liquid Chromatography (UPLC I-Class, Waters Acquity) with a tandem mass spectrometer (MS/MS Waters Xevo TQ-XS) (Waters; Milford, MA, USA) in the MRM mode with an electrospray ion source in the positive mode. The LODs were between 0.08 and 0.10 μg/L (Table S1). The intra-day precision ranged from 1.9 to 7.6% and the inter-day precision ranged from 4.0 to 8.3% depending on the analytes.

The overall quality and accuracy for both analytical methods were monitored by participation in the following interlaboratory programs: The Organic Substances in urine Quality Assessment Scheme (OSEQAS; CTQ/INSPQ, Québec, Canada) for 2,4-D, Glyphosate and AMPA, and the German External Quality Assessment Scheme (G-EQUAS; Erlangen, Germany) for TCPy, PNP, Glyphosate, cis-DCCA, trans-DCCA, cis-DBCA, 3-PBA and 4-F-3-PBA. CTQ/INSPQ has ISO/IEC 17025 and 17,043 accreditation and has run the analyses for cohort and nationally-representative studies, including the Maternal-Infant Research on Environmental Chemicals (MIREC) study and the Canadian Health Measures Survey (CHMS), the Canadian equivalent to the National Health and Nutrition Examination Survey (NHANES) in the U.S. Table S1 shows the specific biomarkers analyzed, their parent pesticide compounds, and the LOD for each analyte.

2.5. *Data analysis*

We calculated the specific gravity of each composite sample as the mean of the specific gravity of the two samples of which the composite was comprised. We imputed values below the LOD as $\frac{LOD}{\sqrt{2}}$ (Hornung et al., 1990) and adjusted urinary concentrations for specific gravity using the following equation: $C_{SG} = C * \frac{1.023-1}{SG-1}$, (Duty et al., 2005) where C_{SG} is the adjusted result (μg/L), C is the original concentration (μg/L), 1.023 is the mean specific gravity measured within the study population, and SG is the mean specific gravity of the individual composite sample. All urinary concentrations henceforth refer to specific gravity-adjusted concentrations from composite samples.

We examined differences in occupational characteristics among men and women using Chi-square tests for categorical variables and two-sided t tests for continuous variables. Urinary biomarker concentrations were non-normally distributed and we used log-transformed concentrations in analyses. We examined differences in biomarker concentrations and associations with occupational characteristics, PPBs, and perceived risk and control using Wilcoxon rank-sum tests. We also ran linear regressions separately with each pesticide biomarker that was detected in at least 65% of participants as the dependent variable, adjusted for gender (man/woman), pesticide applicator status (yes/no), years worked as a farmworker (continuous), and the average number of hours worked in the three days prior to the two study visits (continuous). All analyses were conducted in STATA Version 14.2.

3. Results

We enrolled 62 participants, including 30 men and 32 women. All 62 participants provided one urine sample; 57 (92%) provided two urine samples. Table 1 shows the demographic characteristics of the study population. Of the 30 men, 15 were workers on the H2A visa program (24.1% of overall study population). Participants overwhelmingly identified as Mexican (88.7%), were born in Mexico (95.2%), and were married/living as married (83.9%). Full-time residents (i.e., those living in the U.S. 12 months of the year) had lived in the U.S. for a mean of 22.5 years and H2A visa holders had been coming to the U.S. to work seasonally for a mean of 9.8 years. The average age was 45.1 years, and the majority of participants (64.5%) had an annual household income of less than $40,000. Participants lived in homes with an average of 4.6 people, including an average of 2.6 other agricultural workers.

Table 1

Participant demographic characteristics.

Characteristic	n (%) or Mean (SD)
Gender	
Man	30 (48.4)
Woman	32 (51.6)
Age (years)	
<30	5 (8.1)
30-39	18 (29.0)
40-49	16 (25.8)
50-59	19 (30.1)
≥60	4 (6.5)
Marital status	
Married/living as married	52 (83.9)
Divorced/separated	2 (3.2)
Single	8 (12.9)
Number of people living in house[1]	4.6 (1.6)
Number of agricultural workers living in house[1]	2.6 (1.7)
Annual household income	
<$10,000	2 (3.2)
$10,000–19,999	5 (8.1)
$20,000–29,999	21 (33.8)
$30,000–39,999	12 (19.4)
$40,000–49,999	10 (16.1)
≥$50,000	7 (11.3)
Don’t know/prefer not to answer	5 (8.1)
Ethnic identity	
Mexican	55 (88.7)
Mexican-American	3 (4.8)
Chicano/a	1 (1.6)
Other Hispanic	3 (4.8)
Country of birth	
United States	1 (1.6)
Mexico	59 (95.2)
Guatemala	2 (3.2)
Work status	
H2A worker	15 (24.1)
Non-H2A worker	47 (75.8)
Years living in the U.S./working in the U.S. as H2A worker[2]	20.1 (11.8)

[1] Values include participant responding to questionnaire.

[2] $n = 14$ missing values (don’t know/prefer not to respond).

3.1. Urinary pesticide biomarker concentrations

Table 2 shows the distribution of the urinary pesticide biomarker concentrations for analytes detection in at least 65% of samples in this population (see Table S2 for the distribution of 2,4,5-T, *cis*-DBCA, DEAMPY, IMPY, 3-MPPA, and glufosinate, which were detected in <65% of samples). The analytes 2,4-D, 3-PBA, cis-DCCA, trans-DCCA, and TCPy were detected in 100% of samples; 4-F-3-PBA, MDA, PNP, Glyphosate, and AMPA were each detected in 82–98% samples; and Dicamba was detected in 69% of samples. Men and women had similar distributions of concentrations across all analytes detected in >65% of samples ($p = 0.19$–0.94, depending on the analyte). We observed largely similar distributions in urinary biomarker concentrations after excluding participants who reported that they had sprayed pesticides in the three days prior to either visit ($n = 9$) and one participant who had not worked in the three days prior to either visit. We did not observe consistent associations with pesticide biomarker concentrations in multivariate linear regression models.

Table 3 shows the distribution of urinary concentrations of three pesticide biomarkers, PNP, 3-PBA, and 2,4-D, from this study, the nationally-representative National Health and Nutrition Examination Survey (NHANES), and other studies of farmworkers in the U.S. and Mexico. We chose PNP because some of the other OP metabolites represent exposure to pesticides that have been significantly reduced or phased out in recent years; 3-PBA because it represents exposure to all pyrethroid pesticides; and 2,4-D because it is a common-use herbicide that was detected in all participants in our study. Overall, we saw similar or higher detection frequencies compared with other studies of farmworkers; concentrations were generally higher than in NHANES and were within ranges observed in previous studies of farmworkers.

3.2. Occupational behaviors and training among men and women

Table 4 shows occupational characteristics among all participants and stratified by gender. Men and women each reported working in agriculture for an average of over 16 years. Men reported working significantly more hours per week than women (average 53.9 vs. 45.1, $p < 0.01$) and were significantly more likely to have applied pesticides in the last year or in the three days prior to either study visit ($p < 0.01$ for each). The most common crops participants worked with at the time of the questionnaires were onions, alfalfa, and corn; men and women tended to work on similar crops with the exception of carrots, which were more common among women ($p < 0.01$). In addition to applying pesticides, men were significantly more likely to drive trucks or operate machinery ($p = 0.02$). A slightly higher percentage of women reported performing crop maintenance job tasks, such as weeding and thinning compared to men (78.1% vs. 63.3%, respectively; $p = 0.20$); reporting of all other job tasks was similar between men and women.

Over 90% of participants reported that they usually wore gloves, long pants, a long shirt, and hat while working in the fields. Women were slightly more likely to report typically wearing PPE while working in the fields, though there were not significant differences by gender. When asked in general why they did not wear PPE more often while working in the field, men were more likely to cite factors such as it being too hot outside ($p = 0.04$), the PPE being uncomfortable ($p = 0.01$), and that PPE is not important ($p < 0.01$) compared to women. Approximately 73% of participants had previously attended a pesticide safety

Table 2
Specific-gravity adjusted urinary pesticide concentrations (μg/L)[1,2].

	% > LOD	n	Percentiles					Max	Geometric mean (95% CI)	*p*-value[3]
			10th	25th	50th	75th	90th			
Organophosphate insecticides										
TCPy	100%									
All	100%	62	0.29	0.45	0.67	1.06	2.40	3.25	0.70 (0.58, 0.86)	
Men	100%	30	0.29	0.41	0.66	0.93	2.56	2.75	0.69 (0.53, 0.90)	0.46
Women	100%	32	0.36	0.48	0.69	1.09	2.30	3.25	0.72 (0.53, 0.97)	
MDA[4]										
All	93%	60	0.03	0.06	0.15	0.33	0.60	6.78	0.14 (0.10, 0.19)	
Men	90%	30	0.02	0.05	0.12	0.40	0.65	6.78	0.13 (0.08, 0.22)	0.50
Women	93%	30	0.04	0.07	0.15	0.34	0.55	1.05	0.15 (0.11, 0.22)	
PNP										
All	98%	62	0.47	0.68	1.13	1.58	2.25	4.72	1.04 (0.87, 1.25)	
Men	100%	30	0.54	0.77	1.07	1.49	2.15	2.81	1.08 (0.91, 1.29)	0.94
Women	98%	32	0.35	0.50	1.17	1.92	2.57	4.72	1.00 (0.73, 1.38)	
Pyrethroid insecticides										
3-PBA										
All	100%	62	0.31	0.41	0.78	1.10	2.06	7.48	0.74 (0.60, 0.92)	
Men	100%	30	0.32	0.38	0.74	1.10	1.94	4.39	0.71 (0.53, 0.95)	0.77
Women	100%	32	0.26	0.48	0.79	1.12	2.42	7.48	0.77 (0.55, 1.08)	
4-F-3-PBA										
All	97%	62	0.01	0.01	0.03	0.04	0.06	0.15	0.02 (0.02, 0.03)	
Men	100%	30	0.01	0.01	0.03	0.04	0.07	0.15	0.03 (0.02, 0.03)	0.79
Women	97%	32	0.01	0.02	0.03	0.04	0.06	0.10	0.02 (0.02, 0.03)	
cis-DCCA										
All	100%	62	0.09	0.15	0.24	0.53	1.22	7.36	0.29 (0.23, 0.38)	
Men	100%	30	0.11	0.14	0.24	0.53	0.77	1.42	0.27 (0.20, 0.36)	0.74
Women	100%	32	0.09	0.18	0.25	0.54	1.94	7.36	0.32 (0.21, 0.48)	
trans-DCCA										
All	98%	62	0.17	0.24	0.42	0.74	1.50	8.40	0.46 (0.35, 0.59)	
Men	100%	30	0.17	0.25	0.36	0.66	1.39	2.22	0.43 (0.32, 0.59)	0.76
Women	98%	32	0.15	0.25	0.44	0.85	2.09	8.40	0.49 (0.32, 0.74)	
Herbicides										
2,4-D										
All	100%	62	0.21	0.38	0.75	1.41	2.52	8.72	0.75 (0.59, 0.96)	
Men	100%	30	0.26	0.38	0.87	1.86	2.71	8.72	0.88 (0.61, 1.27)	0.32
Women	100%	32	0.20	0.39	0.69	1.14	2.22	3.50	0.65 (0.47, 0.91)	
Dicamba[5]										
All	67%	58	0.10	0.14	0.25	0.49	1.09	5.95	0.29 (0.23, 0.38)	
Men	79%	28	0.11	0.14	0.28	0.75	1.09	5.95	0.34 (023, 0.51)	0.32
Women	67%	30	0.10	0.12	0.24	0.41	0.76	2.20	0.25 (0.18, 0.35)	
Glyphosate[6]										
All	81%	59	0.08	0.10	0.15	0.34	0.45	3.63	0.18 (0.15, 0.23)	
Men	86%	29	0.08	0.11	0.16	0.35	0.87	3.63	0.21 (0.15, 0.29)	0.53
Women	81%	30	0.08	0.10	0.13	0.33	0.42	0.82	0.17 (0.13, 0.21)	
AMPA										
All	87%	62	0.09	0.17	0.24	0.38	0.63	0.92	0.24 (0.20, 0.29)	
Men	87%	30	0.09	0.21	0.26	0.38	0.74	0.92	0.27 (0.21, 0.34)	0.19
Women	88%	32	0.09	0.15	0.20	0.40	0.54	0.68	0.22 (0.17, 0.28)	

Abbreviations.

[1] Metabolites > LOD in at least 65% of samples.

[2] Machine reading values used for concentrations < LOD.

[3] *p*-value for difference in urinary concentrations between men and women from Wilcoxon rank sum test.

[4] No result due to analytical interference for two participants.

[5] No result due to analytical interference for four participants.

[6] No result due to analytical interference for three participants.

training, as required under the Worker Protection Standards (WPS), with no differences by gender. Twenty percent of participants reported having an experienced an APP, with a slightly higher proportion of women (25.9%) than men (13.8%), though differences by gender were not significant ($p = 0.25$). Self-reported symptoms of APPs reported by participants included headaches, nausea, vomiting, chest pains, and a miscarriage.

3.3. *Risk perceptions among men and women*

Table 5 shows the distribution of participants' agreement with statements regarding pesticide risk perceptions, perceived control, and PPBs among all participants and stratified by gender. Overall, we observed few differences between men and women across these items. The largest difference observed was that men were slightly more likely to agree that showering after work reduces exposure to pesticides ($p = 0.09$). Among all participants, about 31% agreed that "only those who load, mix, or apply pesticides need to protect themselves" and about 50% agreed that "pesticides are only dangerous if you can see or smell them", highlighting potential knowledge gaps regarding the potential for exposure from pesticide residues while working in the fields. Men and women reported similar PPBs, with men being slightly more likely to report changing their clothes (60.0% vs. 53.1%, respectively) or showering (40.0% vs. 25.0%, respectively) immediately after work compared to women.

We observed some potential inconsistencies in participants' perceptions of the risk pesticides posed to themselves compared with the risk to other farmworkers, as well as their beliefs regarding the

Table 3
Distribution of urinary concentrations of select pesticide biomarkers in the current study, NHANES, and other studies of farmworkers.

Metabolite	Study	Study Population	Detection Frequency	Geometric Mean	Percentiles		
					50th	75th	95th
Organophosphate insecticides							
PNP	*Current Study*	60 Latinx farmworkers (32 women, 30 men) in Idaho	98%	1.04	1.13	1.58	2.81
	Curl et al., 2021 [a]	29 Latina farmworkers in Idaho	100%	0.65	0.57	1.98	2.17
	Lopez-Galvez et al., 2018 [b]	20 Latino farmworkers from Sonora, Mexico	100%	1.63	1.62	2.07	2.69
	Raymer et al., 2014 [c,d]	371 men migrant farmworkers in North Carolina	76%	2.94	2.66	N/A	457.00
	NHANES[b]	401 Mexican-Americans from NHANES 2013–2014	N/A	0.71	0.57	1.10	2.33
Pyrethroid insecticides							
3PBA	*Current Study*	60 Latinx farmworkers (32 women, 30 men) in Idaho	100%	0.74	0.78	1.10	2.79
	Curl et al., 2021 [a]	29 Latina farmworkers in Idaho	100%	0.58	0.49	0.94	3.21
	Lopez-Galvez et al., 2018 [b]	20 Latino farmworkers from Sonora, Mexico	100%	1.83	1.69	2.39	4.65
	Arcury et al., 2018a [b,e,f,g]	203 Latino migrant farmworkers in North Carolina (2012)	70%	1.04	1.05	1.87	3.94
	Arcury et al., 2018b [b,e,f,g]	31 Latina farmworkers in North Carolina (2012)	74%	N/A	2.4	3.1	N/A
	Raymer et al., 2014 [c,d]	371 men migrant farmworkers in North Carolina	68%	2.29	1.90	N/A	30.79
	NHANES[b]	418 Mexican-Americans from NHANES 2013–2014	N/A	0.62	0.58	1.25	4.96
Herbicides							
2,4-D	*Current Study*	60 Latinx farmworkers (32 women, 30 men) in Idaho	100%	0.75	0.75	1.41	3.20
	Curl et al., 2021 [a]	29 Latina farmworkers in Idaho	100%	0.35	0.30	0.49	1.55
	Raymer et al., 2014 [c,d]	371 men migrant farmworkers in North Carolina	38%	1.28	1.05	N/A	18.60
	NHANES[b]	426 Mexican-Americans from NHANES 2013–2014	N/A	0.28	0.26	0.47	1.17

[a] Values adjusted for specific gravity.
[b] Values adjusted for creatinine.
[c] Values not adjusted for urinary dilution.
[d] Maximum values, rather than 95th percentile, reported.
[e] Values > Limit of Quantification (LOQ), rather than the LOD, reported.
[f] Mean values, rather than Geometric Mean values, reported.
[g] Collected samples in 2012 and 2013; values shown here are from 2012 assessments.

effectiveness of PPE and their own behaviors, particularly among men. For example, 61% of all participants and 52% of men agreed that their health is harmed by pesticides, compared with 82% of participants and 77% of men, respectively, who agreed that the health of other farmworkers is harmed by pesticides. Further, 97% of men agreed that wearing PPE while working reduces exposure to pesticides but over a third of men indicated that the reason they do not wear PPE more often is because it is not important, though this could be because they do not believe pesticides harm their health.

3.4. *Associations with pesticide biomarker concentrations*

We did not observe consistent associations between urinary pesticide biomarker concentrations and most occupational behaviors and pesticide safety practices, including the use of PPE while working, agricultural duties, current crops participants worked with, behaviors such as removing work boots before entering the home, the number of years participants had worked as a farmworker, visa status (i.e., H2A vs. non-H2A visa holders), or week/month of sample collection (Table S3). Pesticide applicators had slightly higher 2,4-D concentrations than non-applicators (median = 1.40 vs. 0.69); however, results were not statistically significant ($p = 0.13$). Working with onions in the previous three days of either study visit was associated with higher levels of 2,4-D, PNP, Glyphosate, AMPA ($p < 0.01$ for each), and Dicamba ($p = 0.08$).

We observed a few isolated associations of perceived risk and control with increased pesticide biomarker concentrations, however there were not consistent trends across pesticide analytes or participants' beliefs. Participants who disagreed with the statement that they are able to access information about the laws that protect farmworkers from pesticides had higher urinary concentrations of 3-PBA ($p = 0.05$), trans-DCCA ($p = 0.02$), and TCPy ($p = 0.11$), with no significant differences by gender. Participants who agreed with the statement that only those who mix, load, or apply pesticides need to protect themselves had higher concentrations of 2,4-D ($p = 0.11$) and MDA ($p = 0.01$), with significant differences by gender for MDA (p-int = 0.03). Among men, the median specific gravity-adjusted MDA concentration was 0.33 μg/L among those who agreed that only those who load, mix, or apply pesticides need to protect themselves, compared to 0.08 μg/L among men who disagreed with this statement ($p < 0.01$). For women, the median values were 0.11 μg/L and 0.16 among those who agreed and disagreed with this statement, respectively ($p = 0.78$).

4. Discussion

Previous studies have documented high levels of pesticide exposure among farmworkers, however studies to date have focused almost exclusively on men farmworkers (Arcury et al., 2009a, 2009b, 2010a, 2016, 2018a; Krenz et al., 2015; McCauley et al., 2013; Coronado et al., 2004; Habib et al., 2014; Atinkut Asmare et al., 2022). This has resulted in data gaps regarding pesticide exposure among women, who represent an increasing proportion of the agricultural workforce (Atinkut Asmare et al., 2022; Doss) and who have been reported to have higher incidence rates of APP compared with men (Barrón Cuenca et al., 2020; Zhang et al., 2011; Kasner et al., 2012; Calvert et al., 2008; Lekei et al., 2020). This study is one of the first to examine pesticide exposure and risk perceptions among men and women farmworkers, and our findings suggest that external factors (e.g., training, biological susceptibility, decreased control) may uniquely impact women farmworkers' exposure or response to pesticides. Compared to men, women worked significantly fewer hours per week, reported similar or greater levels of PPE use, and were significantly less likely to be pesticide applicators, yet still had very similar urinary concentrations of multiple pesticide biomarkers. We also observed some inconsistencies in perceptions of pesticide risk, particularly among men (e.g., perceiving pesticides as dangerous to other farmworkers but not themselves; agreeing that PPE can reduce pesticide exposure but not wearing PPE more often because it is "not important").

Studies in the US and globally have consistently reported that women have higher rates of APP than men farmworkers (Barrón Cuenca et al., 2020; Zhang et al., 2011; Kasner et al., 2012; Calvert et al., 2008; Lekei et al., 2020). Hypotheses for these discrepancies include factors such as inequitable access to properly fitting PPE (Barrón Cuenca et al., 2020; Calvert et al., 2008; Kunstadter et al., 2001) and pesticide safety trainings; differences in PPBs (e.g., handwashing with soap, showering and

Table 4
Participant occupational characteristics among all participants and stratified by gender (*n* [%] or Mean [SD]).

Characteristic	All (*n* = 62)	Men (*n* = 30)	Women (*n* = 32)	*p*-value[1]
Years worked as farmworker	16.4 (11.5)	16.4 (12.5)	16.3 (10.7)	0.97
Average number of hours worked per week	49.4 (14.2)	53.9 (17.3)	45.1 (8.7)	0.01
Applied pesticides in the last year	12 (19.4)	10 (33.3)	2 (6.3)	<0.01
Worked in fields within 3 days prior to either study visit[2]	61 (98.4)	30 (100.0)	31 (96.7)	0.33
Applied pesticides within 3 days prior to either study visit[2]	9 (15.5)	8 (30.1)	1 (3.1)	<0.01
Crops worked on within 3 days prior to either study visit				
Onions	36 (58.1)	17 (56.7)	19 (59.4)	0.83
Hops	8 (12.9)	3 (10.0)	5 (15.6)	0.51
Alfalfa	31 (50.0)	16 (53.3)	15 (46.9)	0.61
Mint	11 (17.7)	5 (16.7)	6 (18.8)	0.83
Corn	16 (25.8)	9 (30.0)	7 (21.9)	0.47
Carrots	13 (21.0)	1 (3.3)	12 (37.5)	<0.01
Beans	10 (16.1)	6 (20.0)	4 (12.5)	0.42
Wheat	14 (22.6)	9 (30.0)	5 (15.6)	0.18
Job tasks within 3 days prior to either study visit				
Pre-plant prep work (e.g., stringing lines for hops, tilling, irrigation setup and maintenance)	42 (67.7)	21 (70.0)	21 (65.6)	0.71
Crop maintenance (e.g., weeding, thinning)	44 (71.0)	19 (63.3)	25 (78.1)	0.20
Harvesting crops	17 (27.4)	9 (30.0)	8 (25.0)	0.66
Work in a processing facility	6 (9.7)	4 (13.3)	2 (6.3)	0.35
Work in an indoor nursery or greenhouse	3 (4.8)	0 (0.0)	3 (9.4)	0.09
Work in dairy or with livestock	12 (19.4)	7 (23.3)	5 (15.6)	0.44
Truck driver or farm machinery operator	5 (8.1)	5 (16.7)	0 (0.0)	0.02
PPE typically worn while working in the fields (performing activities other than applying pesticides)				
Gloves	59 (95.2)	27 (90.0)	32 (100.0)	0.07
Long pants	58 (93.6)	27 (90.0)	31 (96.9)	0.27
Long shirt	56 (90.3)	26 (86.7)	30 (93.8)	0.35
Hat	60 (96.7)	28 (93.3)	32 (100.0)	0.14
Mask/face covering	35 (56.5)	8 (26.7)	27 (84.4)	<0.01
Reasons for not wearing PPE while working in the fields				
Don't have access	3 (4.8)	1 (3.3)	2 (6.3)	0.59
Not important	10 (16.1)	10 (33.3)	0 (0.0)	<0.01
Too expensive	1 (1.6)	1 (3.3)	0 (0.0)	0.30
It is too hot outside	25 (40.3)	16 (53.3)	9 (28.1)	0.04
PPE doesn't fit properly	5 (8.1)	3 (10.0)	2 (6.3)	0.59
PPE is uncomfortable	24 (38.7)	17 (56.7)	7 (21.9)	0.01
Forget to wear PPE	15 (24.2)	9 (30.0)	6 (18.8)	0.30
Other	8 (12.9)	4 (13.3)	4 (12.5)	0.92
Has attended pesticide safety training	45 (72.6)	22 (73.3)	23 (71.9)	0.89
Has suffered acute pesticide poisoning (self-reported)	12 (20.0)	4 (13.8)	8 (25.9)	0.25

[1] *p*-value from Chi square test (categorical variables) or two-sided *t*-test (continuous variables) for difference by gender.

Table 5
Perceived risk and control and pesticide protective behaviors among all participants and stratified by gender (*n* [%]).

Statement/Behavior[1]	All (*n* = 62)	Men (*n* = 30)	Women (*n* = 32)	*p*-value[2]
Perceived Risk				
Pesticides are safe as long as they are applied correctly	48 (77.4)	24 (80.0)	24 (75.0)	0.64
Only those who load, mix, or apply pesticides need to protect themselves	19 (30.7)	9 (30.0)	10 (31.3)	0.92
Pesticides are only dangerous if you can see or smell them	31 (50.0)	14 (46.7)	17 (53.1)	0.61
Farmworker families have more contact with pesticides than other families	56 (90.3)	26 (86.7)	30 (93.8)	0.35
My health is harmed by pesticides	37 (60.7)	15 (51.7)	22 (68.8)	0.23
The health of other farmworkers is harmed by pesticides	51 (82.3)	23 (76.7)	28 (87.5)	0.26
Women are more likely to be harmed by pesticides than men	20 (32.3)	9 (30.0)	11 (34.4)	0.71
The health of children of farmworkers is harmed by pesticides	51 (82.3)	26 (86.7)	25 (78.1)	0.38
The health of unborn children of farmworkers is harmed by pesticides	48 (77.4)	23 (76.7)	25 (78.1)	0.89
Washing hands while working reduces exposure to pesticides	55 (88.7)	28 (93.3)	27 (84.4)	0.27
Showering after work reduces exposure to pesticides	59 (95.2)	30 (100.0)	29 (90.6)	0.09
Changing clothes after work reduces exposure to pesticides	60 (96.8)	30 (100.0)	30 (93.8)	0.16
Washing clothes after work reduces exposure to pesticides	58 (95.1)	30 (100.0)	28 (90.3)	0.14
Wearing PPE while working reduces exposure to pesticides	61 (98.4)	29 (96.7)	32 (100.0)	0.30
Perceived Control				
There is not much you can do to protect yourself from pesticides	20 (33.3)	9 (30.0)	11 (34.4)	0.71
I believe I have control over avoiding the harmful effects of pesticides	30 (49.2)	15 (51.7)	15 (46.9)	0.54
I can access information about the laws that protect farmworkers from pesticides	48 (77.4)	23 (76.7)	25 (78.1)	0.89
I can access medical care if I get sick from pesticides	55 (88.7)	27 (90.0)	28 (87.5)	0.76
My employer/supervisor would listen to me if I had a concern about pesticides	49 (79.0)	25 (83.3)	24 (75.0)	0.42
The Idaho State Department of Agriculture would listen to me if I had a concern about pesticides	43 (69.3)	21 (70.0)	22 (68.8)	0.92
Protective Behaviors				
Wears work boots inside home	11 (17.7)	6 (20.0)	5 (15.6)	0.66
Washes work clothes with non-work clothes	10 (16.1)	5 (16.7)	5 (15.6)	0.91
Time between finishing work and changing clothes				
Immediately after	35 (56.5)	18 (60.0)	17 (53.1)	0.45
A few hours later	26 (41.9)	11 (36.7)	15 (46.9)	
Many hours later	1 (1.6)	1 (3.3)	0 (0.0)	
Time between finishing work and showering				
Immediately after	20 (32.3)	12 (40.0)	8 (25.0)	0.20
A few hours later	36 (58.1)	14 (46.7)	22 (68.8)	
Many hours later	6 (9.9)	4 (13.3)	2 (6.3)	

[1] *n* (%) who agree with statement or follow behavior.
[2] *p*-value from Chi square test for difference by gender.

changing clothes immediately after work); (Walton et al., 2016) and differences in risk perceptions due to the economic and social positions in which women farmworkers are situated; (Curl et al., 2020; Quandt et al., 2020) however, studies examining these hypotheses are scarce.

We aimed to examine whether these previously reported differences in APP may also correlate with higher day-to-day pesticide biomarker concentrations among women. We found similar urinary concentrations of biomarkers of exposure to a range of agricultural pesticides by gender, despite women working significantly less hours than men, reporting similar or greater levels of training and typical PPE use, and being significantly less likely to directly load, mix, or apply pesticides, which has been associated with higher urinary pesticide concentrations (Curl et al., 2021). There are a number of potential explanations for these findings. First, it is possible that we did not have the power to disentangle the role of factors such as job tasks and pesticide perceptions on urinary concentrations by gender in this relatively small study. Second, it is possible that these findings are unique to this population and that differences may be observed in a larger, more geographically diverse and heterogenous population. For example, factors such as farm work experience likely play a role in pesticide risk perceptions and the adoption of PPBs; (Walton et al., 2017b) our population had relatively high levels of farm work experience, with both men and women having worked as a farmworker for an average of 16 years, which may not be representative of the general farmworker population.

Taken with previous work, our findings also suggest that external factors may be contributing to differences in women farmworkers' exposure and/or vulnerability to pesticides compared with men. A study of farmworkers in Bolivia reported that women were significantly less likely to apply pesticides than men, yet had largely similar concentrations of various pesticide biomarkers and were more likely to report signs of an APP (Barrón Cuenca et al., 2020). Consistent with these findings and with previous surveillance data, (Kasner et al., 2012) women who reported having experienced an APP in our study were not pesticide applicators; among men that reported an APP in our study, two were pesticide applicators and two were non-applicators. While the literature on women farmworkers is still scarce, these findings suggest a potential phenomenon in which men are more likely to be pesticide applicators, yet women experience similar or higher levels of occupational pesticide exposure and APPs. We identified some potential explanations that should be explored in future studies.

First, it is possible that differences in job tasks by gender impact pesticide exposure. In our study, men were significantly more likely to perform tasks such as driving trucks or operating machinery, which likely has lower potential for pesticide exposure than tasks such as weeding and thinning crops, which was slightly more common among women. Interconnected with this, a number of women from our study anecdotally reported that they had been poisoned from aerial pesticide spraying, and it is possible that women are more likely to work with or near crops that are sprayed aerially, potentially increasing the risk for acute poisoning if proper precautions are not followed. Second, it is possible that women may be more biologically susceptible to pesticides than men (London et al., 2002; García, 2003b) due to factors such as differences in pesticide metabolization, particularly during periods such as pregnancy; (Fortin et al., 2013) higher relative levels of adipose tissue; (Le Magueresse-Battistoni, 2020; Wang et al., 2021) and interference with female hormonal function (Bretveld et al., 2006a, 2006b, 2006c; García, 2003a). Third, women may be more likely to report APPs than men; however, this alone does not explain why women had similar urinary concentrations while working less hours than men. There may also be differences in access to pesticide safety trainings and PPE by gender that we were not able to fully disentangle in this pilot study. Women reported similar or slightly higher use of PPE compared to men in our study, however other studies have reported that women are less protected while working (Barrón Cuenca et al., 2020). Further, one of our hypotheses was that women might not have access to properly fitting PPE. While most (~87%) of women in our study said that they do have access to PPE in their size, future studies should consider visually examining participants' PPE and assessing fit. Finally, it is possible that women were more likely to recall an APP due to the impact of the event (e.g., one participant reported experiencing a miscarriage as a result of an APP). It is possible that a combination of these and other factors are contributing to potential gender-specific susceptibility of occupational pesticide exposure that should be examined in larger studies.

Overall, we observed trends of higher urinary pesticide biomarker concentrations among our population compared with the general US population represented by NHANES; detection frequencies and geometric mean and median values were largely within ranges reported in previous studies of farmworkers, however concentrations at the 95th percentile were lower than some previous studies examining occupational exposure (Arcury et al., 2018a, 2018b; López-Gálvez et al., 2018; Raymer et al., 2014). Notably, it is difficult to make direct comparisons in urinary pesticide concentrations across different studies due to factors such as differences in analytical methods and correction for urinary dilution, differences in pesticide use over time, and differences in crops and pesticides used across geographic regions; thus, comparisons across different studies should be interpreted with caution.

We observed similar levels of perceived control among men and women in our study, with about half of participants agreeing they had control to avoid the harmful effects of pesticides. However, we did observe some trends of inconsistencies in perceived risk and protective behaviors among men in this study. It is difficult to compare gender-specific findings with previous studies given the scarcity of the literature on this topic; however, other studies have reported disconnects in risk perceptions, perceived control, and behaviors among farmworkers more broadly, without assessing differences by gender (Cabrera et al., 2009; Edelson et al., 2018; Strong et al., 2008). One study of 40 migrant farmworkers in Pennsylvania, including 39 men, reported findings similar to ours in which participants often categorized other farmworkers at risk of pesticide exposure, but not themselves (Edelson et al., 2018). Similarly, an investigation of 260 women working in nursery and fernery operations found that participants who perceived they were never in contact with pesticides had the highest urinary OP concentrations, and those who perceived they were in contact with pesticides every day had the lowest concentrations (Runkle et al., 2013). Taken together, these findings suggest that even those who have received required WPS training may not accurately perceive their potential for pesticide exposure or its health impacts. Studies in Nepal and China that have assessed gender-specific pesticide knowledge, risk awareness, and practices have reported that women had lower levels of pesticide safety knowledge and awareness, (Wang et al., 2017; Atreya, 2007) whereas men implemented fewer protective behaviors while working with pesticides (Wang et al., 2017).

In addition to assessing pesticide perceptions and adoption of PPBs, it is imperative to assess barriers to pesticide protection. Men and women reported similar levels of having received pesticide safety training; while this does not support our hypothesis that women may have less access to trainings than men, participants did voice concerns regarding the quality of training and reported wanting more in-person training. Future studies should assess the format and frequency of instruction needed to best support farmworkers in learning and retaining information regarding how to protect themselves from pesticides.

Notably, previous studies suggest that self-efficacy to prevent pesticide exposure is a critical determinant of protective behaviors, regardless of the level of risk communication and perceived risk (Cabrera et al., 2009; Arcury et al., 2002b; Trejo et al., 2013). As others have argued, (Arcury et al., 2002b) information on pesticide risk and protective behaviors will only be effective if farmworkers have control over adopting PPBs inside and outside of the workplace. Farmworkers' control to mitigate pesticide exposure and adopt PPBs may be impacted by structural factors such as migration/documentation status, English proficiency, pay type (e.g., hourly vs. piece-rate pay), gender, work experience, and the regulatory environment (Blackman, 2012; Arcury et al., 2007). Thus, the burden for pesticide protection should not be placed on individual farmworkers, but rather the focus should be on systematic inequities and structural factors influencing farmworkers' control, as well as the regulatory environment that shapes the safety of agricultural workplace environments, irrespective of individual behaviors.

Specifically, future studies should examine additional upstream factors such as the adequacy of current regulations to protect farmworkers from pesticides, gaps in enforcement of current regulations (e.g., ensuring that workers are not in or near fields during aerial pesticide application), and the need for additional regulations. While some have argued that current pesticide safety regulations are insufficient, (Brennan et al., 2015; Snipes et al., 2009; Donley, 2019; Centner, 2021) it is also clear that enforcement is often lacking (Snipes et al., 2009; Centner, 2021). For example, participants in our study reported various indications of lack of workplace compliance with WPS regulations, such as inconsistent access to handwash stations and notifications of pesticide applications, which we will explore in a future analysis. Even the way in which the evaluation of regulatory compliance is structured at the national and state levels creates gaps for monitoring compliance. The EPA has largely delegated the enforcement of pesticide regulations to states; however, in many states, such as Idaho, the lead enforcement agency is a department of agriculture, which may not have the resources or jurisdiction to focus regulatory efforts on pesticide safety for farmworkers (Guarna, 2022).

These concerns over farmworkers' ability to adopt protective behaviors will only be intensified with climate change. Consistent with previous studies citing concerns such as comfort, (Cabrera et al., 2009; Levesque et al., 2012; Snipes et al., 2009) one of the most common reasons that men in our study reported not wearing PPE more often was that it is too hot outside or that the PPE is uncomfortable. Emerging evidence indicates that extreme heat may increase the body's susceptibility to pesticides and other toxicants, (Hooper et al., 2013; Balbus et al., 2013) amplifying the need for PPE, which could in turn increase the risk of heat-related injury. Further, from a regulatory perspective, the EPA is tasked with ensuring pesticide safety whereas the Occupational Safety and Health Administration (OSHA) is the lead jurisdiction for addressing exposures such as heat, (Guarna, 2022) introducing additional barriers in developing and enforcing health protective policies to address co-occurring climate-intensified exposures.

We did not observe consistent associations of PPBs or perceived risk or control with pesticide biomarker concentrations in our study; however, we had a small sample size and relatively low variability in both biomarker concentrations and questionnaire responses regarding adoption of PPE and protective behaviors. Further, we often asked about the use of PPE and adoption of PPBs dichotomously (e.g., "do you typically wear a long shirt while working"), which may not capture important variability, such as if a participant wore a long shirt during part of the day, and could make it more difficult to elucidate relationships with pesticide concentrations. Previous observational and intervention studies have consistently shown that factors such as wearing protective equipment (Barrón Cuenca et al., 2020; Walton et al., 2016; Fuhrimann et al., 2020; Levesque et al., 2012; López-Gálvez et al., 2018; Furlong et al., 2015; Salvatore et al., 2008; Quandt et al., 2006; Hernández-Valero et al., 2001; Bradman et al., 2009) and adopting protective behaviors endorsed by WPS (Salvatore et al., 2008; Bradman et al., 2009; Curwin et al., 2003; Arcury et al., 2005) are associated with lower urinary pesticide biomarker concentrations and could potentially decrease the risk of adverse health outcomes (Furlong et al., 2015; Zahm et al., 1990). Further, evidence suggests that access to trainings and resources are important determinants of the adoption of these PPBs, underscoring the importance of robust training to reduce the risk of pesticides. For example, previous studies have reported greater use of PPE among those who had access to equipment from their employer, (Walton et al., 2017b; Strong et al., 2008; Ciesielski et al., 1994) and that farmworkers with greater knowledge of protective behaviors engage in work-related PPBs more frequently (Strong et al., 2008).

Findings from this study should be interpreted in light of various limitations. This was a relatively small pilot study that characterized very recent pesticide exposure in a limited geographic setting. We are not alone in these limitations; previous investigations examining occupational pesticide exposure among farmworkers have primarily been cross-sectional and have characterized exposure based on the collection of one or two biological samples per season, which cannot reflect participants' chronic exposure. While we attempted to minimize the impact of the short half-lives and high inter- and intra-individual variability of the metabolites analyzed by collecting two urine samples within a seven-day period, the urine samples still reflect exposure recent to the time of sampling. Further, we did not assess other sources of pesticide exposure in the questionnaire, such as diet or residential proximity to agricultural fields. Larger studies with serial urine collection are necessary to more robustly examine chronic occupational pesticide exposure and associations with protective behaviors, risk perception, and perceived control.

This study also relied in part on snowball sampling to recruit participants and this population may not be generalizable to the wider Latinx farmworker population in Idaho or the rest of the US. Future studies should examine these questions in populations who more recently entered the agricultural workforce and may better represent the general farmworker population, particularly for women. Further, some participants lived together (e.g., some were married or shared H2A housing) or worked on the same crew at the same farms, and thus likely had correlated urinary pesticide concentrations. In order to maximize participants' confidentiality and minimize concerns such as fear of losing their job or pay, which have been widely documented in this structurally marginalized population, (Cheney et al., 2022; Caxaj et al., 2019; Arcury et al., 2010b) we intentionally did not ask participants about which farms they worked at or who employed them. Thus, we are unable to assess statistical independence of the study sample, but we did attempt to recruit participants from a broad geographic region in Southeast Idaho.

In addition to these limitations, it is important to note that Idaho had an unusual agricultural season in 2022 that was delayed due to unprecedented precipitation and cold weather (Fare, 2022). While we delayed the enrollment of participants in order to capture exposures during the pesticide spray season and did not observe any differences in biomarker concentrations by the week or month of sample collection, it is still possible that the observations from this particular study may not necessarily be generalizable to other agricultural seasons or geographic locations.

This study also has a number of strengths. We are one of the few studies to combine urinary pesticide biomonitoring and assessment of farmworkers' pesticide risk perceptions, perceived control, protective behaviors, and barriers to increasing protection, and one of the first to do so in a cohort balanced on gender. This study also contributes to our understanding of occupational pesticide exposure among farmworkers; despite the widespread use of pesticides in agriculture, this is still one of relatively few studies to report concentrations of a range of pesticide biomarkers in an occupational population, and one of only a handful to do so in Idaho, which has a large but understudied agricultural population. We had high levels of follow-up in this hard-to-reach population, with over 90% of participants completing both study visits.

5. Conclusions

Our study contributes to the very scarce literature examining pesticide exposures and risk perceptions among women farmworkers, and our results indicate that women may have unique exposure and/or vulnerability to pesticides. Given the increasing proportion of women in the agricultural workforce in the U.S. and worldwide, larger studies examining gender-specific pesticide exposure and barriers to pesticide protection are urgently needed. Future studies should also consider structural factors shaping farmworkers' control to adopt protective behaviors and regulatory gaps that shape the overall safety of agricultural workplace environments, irrespective of farmworkers' individual behaviors.

Declaration of conflicts of interest

The authors declare they have no actual or potential conflicts of interest.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.ijheh.2023.114275.

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