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The association between awareness and behavior concerning the need for protection when using pesticide sprays and neurologic symptoms
A latent class cluster analysis

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Abstract

Pesticide exposure is a major health risk factor among agricultural workers, and poor protective behavior and a lack of awareness concerning the risks of pesticide use in developing countries may increase the intensity of pesticide exposure. This cross-sectional study aimed to explore the relationship between neurologic symptoms and protective behavior and awareness in relation to pesticide use in China. Latent class cluster analysis was used to categorize participants into 3 latent cluster subgroups, namely, a poor protective behavior subgroup, an excellent protective awareness and behavior subgroup, and a poor protective awareness subgroup, using a person-centered approach. Multivariate regression models were used to detect the association between the latent class cluster subgroups and self-reported neurologic symptoms. The results showed that poor protective behavior in pesticide use was an important negative predicator of neurologic symptoms such as reduced sleep quality, frequency of nightmares, debility, hypopsia, and hypomnesis. These findings suggest that targeted interventions for agricultural workers, especially local greenhouse farmers, are urgently needed to improve pesticide protection behavior.

Abbreviations: aBIC = sample-size adjusted BIC, AIC = Akaike information criterion, BIC = Bayesian information criterion, Hyg = personal hygiene habits after spraying, LCA = latent class analysis, LL = log likelihood, PPE = protective measures using pesticide.

Keywords: behavior, latent cluster analysis, neurological symptoms, pesticide, protection awareness

1. Introduction

Pesticide has been widely used in the agricultural sector because of its superiority in preventing and controlling the pests.[1] An association between pesticide exposure and adverse health effects has been reported within developing countries,[2–4] frequently because of a lower level of protection awareness and lack of suitable equipment, as well as insufficient information on the correct specifications for pesticide use in the spraying process for farmers. As in developing countries,[5–7] pesticide misuse has also occurred in China, because of erroneous perceptions concerning

pesticide use and subsequent high-risk behavior among farmers and other agricultural workers. During the farming process, frequent inappropriate use of pesticides has been reported among low- and middle-income communities, especially in rural areas.[8] Overall, pesticide poisoning caused through ignoring or deliberately not following pesticide spray regulations has been acknowledged as a serious public health concern in agricultural communities.[3,9]

In contrast to open-field agricultural practices, greenhouse farming has several distinctive features, such as relative spatial isolation, high temperature and humidity, and a long-term operational timeframe, involving a greater likelihood of introducing significant amounts of hazardous substances into the air and, therefore, an increased risk owing to higher pesticide exposure intensity. Subsequently, adverse health effects as a consequence of cumulative poisoning are more likely to emerge. Concerning greenhouse farmers, a poor knowledge of spray use and a lower rate of awareness and appropriate practice related to pesticide protection have been reported in outlying areas in Yinchuan, China.[10] Despite efforts made by the Chinese government to promote the safe use of pesticide sprays,[11] abuse and improper use of pesticide sprays among farmers remain widespread. To date, few studies have examined the association between pesticide spray behavior and awareness and health outcomes among the farmers, especially those involved in vegetable greenhouse farming, in China. However, and particularly in relation to neurologic outcomes, such as sleep disorders, obtaining relevant evidence to assess the association between pesticide spray behavior and protection awareness appears necessary.

As distinct from creating subjectively based divisions or using a variable-centered dimensionality reduction method, latent class analysis (LCA) is a "person-centered" approach that groups similar individuals into categories.[12] Its advantage lies in categorizing a population into distinct groups based on objectively determined distribution features and characteristics, which enhances data quality and accurate assessment. In recent years, LCA has been used in psychology, birth defect screening,[13,14] health assessments, and in relation to high-risk populations identified as requiring clinical treatment.[15] Although LCA has been used more often in the public health domain, it has also been used in occupational epidemiology. This study aimed to assess the distribution of neurologic symptoms among latent clusters that were split in terms of pesticide use behavior and awareness characteristics.

2. Materials and methods

2.1. Data source and study design

A cross-sectional study was conducted from 2015 to 2017 in Yinchuan city, in western China. Four long-term co-operative vegetable greenhouse villages were selected as investigation sites, and, in each year, a different "team" (a "team" refers to a basic operational unit in Chinese rural areas, with one village usually providing at least three teams) was selected to be surveyed, using a simple sampling method.

Adults aged >18 years who had lived at their current address for at least 5 years and who had been engaged in vegetable farming in greenhouses for >1 year were eligible for inclusion in the study. All eligible villagers in the sample teams were invited to participate and a total of 1368 greenhouse farmers agreed to take part in the study. The study design and protocol were approved by the Medical Ethics Committee of Ningxia Medical University (No. 2014-090), and verbal consent was obtained from participants before the investigation.

2.2. Protective awareness and behavior in relation to pesticide spray use

A 12-question questionnaire was used to estimate the extent of protective awareness and behavior concerning pesticide use among the participants, and the corresponding information was collated by a trained investigator. The details on information derived from the questionnaire are shown in Table 1. In the subsequent analysis and in accordance with previous research[16,17], a comprehensive index reflecting pesticide protective awareness and behavior has been calculated, based on the variables derived from Table 1.

2.3. Neurological symptoms

Sleep disorders and debility, hypopsia, hypomnesis, loss of interest, and dizziness were considered as neurological symptoms. The related information derived from the questionnaires is shown in Table 2.

2.4. Covariates

The covariates of interest included demographic and socioeconomic factors, diagnosed history of disease, lifestyle and dietary habits, and basic information concerning the participants' involvement in greenhouse vegetable farming. Demographic and socioeconomic factors comprised family size, sex, ethnicity, age, educational level, marital status, and household income. Information collected on diagnosed history of disease included whether chronic disease had been diagnosed >1 year before or diagnosed within the previous year. Information on lifestyle and dietary habits, such as smoking status, frequency of alcohol consumption, exercise habits, and breakfast habit s, and on the participants' salt intake situation, was collected, as well as basic information on their involvement in greenhouse vegetable farming, such as the number of years spent in greenhouse farming, the per capita planting area they worked within, and the number of working hours spent in the greenhouse each day. The descriptions and distribution of the covariates are shown in Table S1, http://links.lww.com/MD/D140.

2.5. Statistical analysis

Latent class cluster analysis (LCA) was used to identify potential clusters of individuals with similar profiles within the 10 selected variables in relation to protective awareness and behavior concerning pesticide spray use. LCA analysis was performed using Mplus version 7.4 (Linda Muthén & Bengt Muthén). The best model was chosen according to goodness-of-fit indicators, such as BIC (Bayesian information criterion), AIC (Akaike information criterion), aBIC (sample-size adjusted BIC), and entropy (ranging from 0 to 1). A smaller BIC, AIC, and aBIC indicate a better model; higher entropy shows a higher classification accuracy.

Descriptive statistics included frequency and percentiles for categorical variables, and arithmetic mean and standard deviation for continuous variables. Analysis of variance (ANOVA), a χ^2 test, and Fisher exact test were used to assess differences among latent clusters for continuous and categorical variables, respectively. Multivariate regression models such as multinomial logistic regression, ordinal logistic regression, or linear regression were employed to detect the association between differing pesticide spray awareness and behavior clusters and neurological symptoms. A latent cluster was set as a dummy variable in the models, with cluster 2 set as the reference group. When the proportion odds assumption was met, then ordinal logistic regression was selected; otherwise multinomial logistic regression was used. All these analyses were performed using Stata version 15.0 (STATA Corporation, College Station, TX).

In multivariate regression analysis, hypnotic drug use and sleep apnea were categorized into 2-level variables (Yes and No), because of 15 participants reporting that they needed medication to help with sleeping, and 5% of participants reporting sleep apnea. A Poisson regression model was used to explore the association between neurologic symptoms and awareness and behavior concerning pesticide use. Regarding neurologic symptoms, only 2 participants reported serious debility, whereas 1 participant initially reported serious hypomnesis, and then reduced it to moderate level. Eight different confounding-adjusted models were employed.

3. Results

3.1. LCA results: clustering of pesticide spray behavior and awareness factors

In this study, 5 cluster models were considered, and the comparison results are shown in Table 3. Model 3 had lower

Table 1

Questions, response options, and items concerning pesticide spray behavior and awareness.

Questions	Response options and scores	Questionnaire items
Are you using mixed pesticides?	Never used mixing=0	Mixing status
	Less than 50% of the time=3	
	More than 50% of the time=9	
How do you spray pesticides?	Hand spray=8	Application method
	Machine Spray=1	
	Mix spray=4	
In the process of spraying, do you engage in the following behavior?	Drink water=3	Spray-use behavior
	Eating=3	
	Smoking=2	
	Chat=1	
	None=0	
What are the protective measures you use when using pesticides? (multiple choice)	PPE-0=1	PPE
	PPE-1=0.8	
	PPE-2=0.7	
	PPE-3=0.6	
	PPE-1 & PPE-2=0.5	
	PPE-1 & PPE-3=0.4	
	PPE-2 & PPE-3=0.3	
	PPE-1 & PPE-2 & PPE-3=0.1	
Question 1: After spraying pesticide, when do you usually clean or change into clean clothes?	Question 1:	Hyg
Question 2: When do you take a shower after spraying pesticides?	Immediately=1	
Question 3: When do you wash your hands after spraying pesticide?	Change the clothes that day=2	
	Don't change clothes never=3	
	Question 2 & Question 3:	
	Immediately=1	
	The same day=2	
	Not in the same day=3	
What percentage of time do you spend spraying pesticides by yourself?	Never=1	Spray time proportion
	Less than half=2	
	More than half=3	
How often do you spray pesticide on average?	Days	Spray interval
How long does it take you to spray the pesticide on average?	Hours	Time spent spraying
Do you have the habit of checking for leakage of pesticide before spraying?	Yes=0	Check before
	Didn't pay attention=2	
	None=6	
Do you have the habit of checking for leakage of pesticide during spraying?	Yes=0	Check during
	Didn't pay attention=2	
	None=6	

Hyg=personal hygiene habits after spraying, PPE=protective measures using pesticide.

Table 2

Questions, items, and response options concerning neurological symptoms.

Measurement	Questionnaire items	Response options
Sleep duration	In the last month, how long have you slept per night on average?	
Sleep quality	How do you think your sleep quality has been in the last month?	Excellent=1, good=2, worse=3, much worse=4
Hypnotic drug use frequency	How often have you used hypnotic drugs in the last month?	None=1, less than once a wk=2, 1–2 times per wk=3, ≥3 times per wk=4
Difficulty falling asleep	How often have you had trouble falling asleep in the last month? (failure to fall asleep within 30 min)	
Sleep apnea	How often have you had sleep apnea in the past 30 days?	
Nightmares	How often have had nightmares in the last 30 days?	
Suffering from difficulty in falling asleep	How often have you suffered difficulty in falling asleep in the last 30 d?	
Debility		None=1, mild=2, moderate=3, serious=4, very serious=5
Hypopsia		
Hypomnesis		
Loss of interest		
Dizziness		

Goodness-of-fit measurements of 5 different cluster models in relation to pesticide spray protection awareness and behavior.

Model	LL	BIC	aBIC	AIC	Entropy
1-Cluster	−22,202.23	44,548.89	44,485.36	44,444.47	1.000
2-Cluster	−20,160.59	40,545.04	40,446.57	40,383.19	1.000
3-Cluster	−19,112.62	38,528.53	38,395.12	38,309.15	0.999
4-Cluster	−18,780.51	37,943.74	37,775.38	37,667.02	0.970
5-Cluster	−18,593.85	37,649.86	37,446.55	37,315.70	0.982

aBIC = sample-size adjusted BIC, AIC = Akaike information criterion, BIC = Bayesian information criterion, LL = log likelihood.

log likelihood (LL), BIC, aBIC, and AIC compared with Model 1 and Model 2 and, compared with Model 4 and Model 5, it had higher entropy value. Given that the reduction from Model 3 to Model 4 was slight, we then selected 3 clusters as the target number of latent clusters.

Figure 1 shows the cluster-specific probabilities of pesticide spray behavior and protective awareness for the 3-cluster model. Cluster 1 showed a high score for not checking the spray machine before and during the spray procedure, indicating poor awareness for this Cluster 1 subgroup (the poor awareness subgroup), which comprised 177 participants and accounted for 12.94% of the overall participants. Cluster 2 showed a lower score across all 10 items, indicating excellent protective awareness and behavior for this Cluster 2 subgroup (the excellent protection subgroup), which comprised 1078 participants and accounted for 78.80% of the overall participants. A high score for inappropriate behavior while spraying was detected in Cluster 3, indicating poor behavior for this Custer 3 subgroup (the poor behavior subgroup), which comprised 113 participants and accounted for 8.26% of the overall participants.
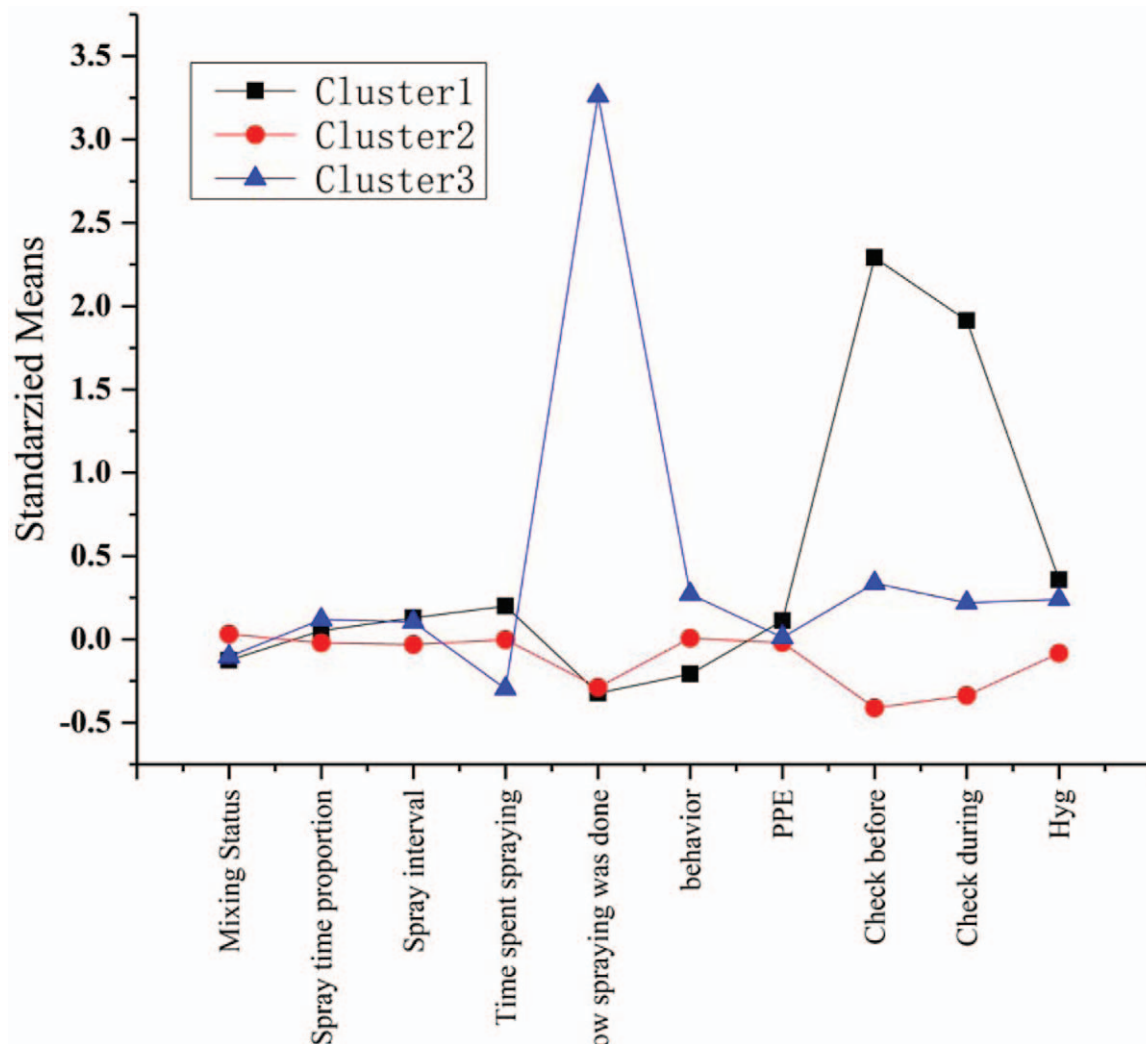

Figure 1. Cluster-specific probabilities concerning pesticide spray behavior and protective awareness for the three-cluster model (n = 1368, greenhouse farmers from Yinchuan, China). Hyg = personal hygiene habit after spray, PPE = protective measures in pesticide.

3.2. Basic information distribution among the clusters

Demographic information concerning each cluster is shown in Table 4. Information concerning the number of family members, income status, and days spent working in the greenhouse differed significantly among the 3 clusters. More participants with higher incomes were found in the excellent protection subgroup than in the other subgroups. Less protective behavior in the poor behavior subgroup was related to a lower number of days working in the greenhouse compared to the other 2 groups.

Table 4

Demographic and socioeconomic information distribution and differences among the clusters.

Variables	Poor awareness	Excellent protection	Poor behavior	F/χ^2	P
Number of family members				11.224	.024
≤2	16 (9.09%)	114 (10.64%)	9 (7.96%)		
3	27 (15.34%)	176 (16.43%)	32 (28.32%)		
≥4	133 (75.57%)	781 (72.92%)	72 (63.72%)		
Sex				0.415	.813
Male	95 (53.67%)	568 (52.69%)	63 (55.75%)		
Female	82 (46.33%)	510 (47.31%)	50 (44.25%)		
Ethnicity				3.284	.194
Han	157 (88.70%)	950 (88.13%)	106 (93.81%)		
Hui	20 (11.30%)	128 (11.87%)	7 (6.19%)		
Age (mean ± SD)	46.80 ± 10.20	46.79 ± 10.83	47.00 ± 9.39	0.020	.980
Education				5.044	.538
No formal school education	55 (31.07%)	293 (27.21%)	26 (23.01%)		
Primary school	61 (34.46%)	339 (31.48%)	37 (32.74%)		
Junior high school	51 (28.81%)	371 (34.45%)	44 (38.94%)		
High school and above	10 (5.65%)	74 (6.87%)	6 (5.31%)		
Marital status				0.007	.996
Married	168 (94.92%)	1021 (94.80%)	107 (94.69%)		
Unmarried/other	9 (5.08%)	56 (5.20%)	6 (5.31%)		
Years of local residence				10.487	.106
1–5	46 (25.99%)	328 (30.51%)	43 (38.05%)		
5–10	35 (19.77%)	245 (22.79%)	18 (15.93%)		
10–15	7 (3.95%)	46 (4.28%)	8 (7.08%)		
>15	89 (50.28%)	456 (42.42%)	44 (38.94%)		
Diagnosed diseases >1 y previously				0.455	.796
No	145 (81.92%)	871 (80.95%)	89 (78.76%)		
Yes	32 (18.08%)	205 (19.05%)	24 (21.24%)		
Diagnosed diseases in the recent y				4.133	.127
No	166 (93.79%)	985 (91.54%)	109 (96.46%)		
Yes	11 (6.21%)	91 (8.46%)	4 (3.54%)		
Income group				23.086	.001
<4000 CNY	41 (23.16%)	245 (22.73%)	22 (19.47%)		
4000–10,000 CNY	35 (19.77%)	245 (22.73%)	43 (38.05%)		
10,000–20,000 CNY	63 (35.59%)	281 (26.07%)	22 (19.47%)		
≥20,000 CNY	38 (21.47%)	307 (28.48%)	26 (23.01%)		
Smoking status				5.796	.446
Every day	56 (31.64%)	394 (36.62%)	41 (36.28%)		
Not every day	3 (1.69%)	16 (1.49%)	3 (2.65%)		
Former smoker, now quit	4 (2.26%)	53 (4.93%)	5 (4.42%)		
Never	114 (64.41%)	613 (56.97%)	64 (56.64%)		
Alcohol consumption status				1.738	.784
>30 days ago	23 (12.99%)	171 (15.91%)	16 (14.16%)		
Within the last 30 days	43 (24.29%)	232 (21.58%)	23 (20.35%)		
Never consume alcohol	111 (62.71%)	672 (62.51%)	74 (65.49%)		
Physical exercise habits				1.797	.407
No	141 (81.03%)	891 (84.45%)	87 (81.31%)		
Yes	33 (18.97%)	164 (15.55%)	20 (18.69%)		
Breakfast habit				3.756	.710
Almost everyday	106 (60.23%)	633 (58.88%)	74 (65.49%)		
Occasionally	24 (13.64%)	163 (15.16%)	14 (12.39%)		
Rarely	18 (10.23%)	87 (8.09%)	10 (8.85%)		
Never	28 (15.91%)	192 (17.86%)	15 (13.27%)		
Planting y (mean ± SD)	8.93 ± 5.55	8.32 ± 5.76	7.96 ± 5.25	1.179	.308
Average area (mean ± SD)	1.69 ± 1.81	1.90 ± 4.51	2.17 ± 3.88	0.448	.639
Time spent in greenhouse, days				15.966	.014
<100 days	8 (4.52%)	15 (1.39%)	1 (0.88%)		
100–199	30 (16.95%)	163 (15.12%)	27 (23.89%)		
200–299	42 (23.73%)	304 (28.20%)	30 (26.55%)		
≥300	97 (54.80%)	596 (55.29%)	55 (48.67%)		

3.3. Results of Comparing neurologic symptoms among the 3 clusters

Seven sleep-related neurological symptoms and 5 self-rated other issues were compared among the 3 latent clusters, as shown in Table 5. Sleep quality, nightmare frequency, and sleep disorder frequency showed significant variations among the clusters. Higher nightmare frequency was found in the poor behavior subgroup than in the other 2 groups, and greater sleep disorder frequency occurred in the poor awareness subgroup.

All the 5 other neurologic symptoms showed significant distribution, with a high frequency of weakness, hypopsia, and hypomnesis observed in the poor behavior subgroup and a high frequency of dizziness in the poor awareness subgroup. Interestingly, there was moderate-frequency loss of interest

Table 5

Distribution of neurologic symptoms and differences in relation to awareness and behavior concerning pesticide use among the latent cluster subgroups.

Neurologic symptoms	Poor awareness	Excellent protection	Poor behavior	F/χ^2	P
Sleep duration (mean ± SD)	7.80 ± 1.45	7.5 9 ± 1.38	7.51 ± 1.10	2.082	.125
Sleep quality, n (%)				18.864	.004
Excellent	88 (49.72%)	495 (45.92%)	36 (31.86%)		
Good	72 (40.68%)	420 (38.96%)	65 (57.52%)		
Worse	15 (8.47%)	137 (12.71%)	11 (9.73%)		
Much worse	2 (1.13%)	26 (2.41%)	1 (0.88%)		
Hypnotic drug use, n (%)				8.842	.116
None	175 (98.87%)	1068 (99.07%)	110 (97.35%)		
Less than once a wk	1 (0.56%)	5 (0.46%)	3 (2.65%)		
1–2 times per wk	0 (0.00%)	4 (0.37%)	0 (0.00%)		
≥3 times per wk	1 (0.56%)	1 (0.09%)	0 (0.00%)		
Difficulty falling asleep, n (%)				4.525	.606
None	145 (81.92%)	885 (82.10%)	99 (87.61%)		
Less than once a week	11 (6.21%)	66 (6.12%)	7 (6.19%)		
1–2 times per wk	10 (5.65%)	48 (4.45%)	4 (3.54%)		
≥3 times per wk	11 (6.21%)	79 (7.33%)	3 (2.65%)		
Sleep apnea, n (%)				9.288	.117
None	166 (93.79%)	1021 (94.71%)	106 (93.81%)		
Less than once a wk	4 (2.26%)	23 (2.13%)	7 (6.19%)		
1–2 times per wk	5 (2.82%)	22 (2.04%)	0 (0.00%)		
≥3 times per wk	2 (1.13%)	12 (1.11%)	0 (0.00%)		
Nightmares, n (%)				28.381	<.001
None	100 (56.50%)	623 (57.79%)	56 (49.56%)		
Less than once a wk	42 (23.73%)	271 (25.14%)	51 (45.13%)		
1–2 times per wk	14 (7.91%)	88 (8.16%)	4 (3.54%)		
≥3 times per wk	21 (11.86%)	96 (8.91%)	2 (1.77%)		
Suffering from sleep disorders, n (%)				16.780	.007
None	149 (84.18%)	971 (90.07%)	104 (92.04%)		
Less than once a wk	14 (7.91%)	43 (3.99%)	1 (0.88%)		
1–2 times per wk	3 (1.69%)	32 (2.97%)	6 (5.31%)		
≥3 times per wk	11 (6.21%)	32 (2.97%)	2 (1.77%)		
Debility, n (%)				13.360	.032
None	75 (42.37%)	489 (45.36%)	44 (38.94%)		
Mild	84 (47.46%)	466 (43.23%)	64 (56.64%)		
Moderate	17 (9.60%)	122 (11.32%)	5 (4.42%)		
Serious	1 (0.56%)	1 (0.09%)	0 (0.00%)		
Hypopsia, n (%)				17.161	.002
None	96 (54.24%)	575 (53.34%)	50 (44.25%)		
Mild	5 3(29.94%)	369 (34.23%)	57 (50.44%)		
Moderate	28 (15.82%)	134 (12.43%)	6 (5.31%)		
Hypomnesis, n (%)				15.840	.012
None	81 (45.76%)	530 (49.17%)	43 (38.05%)		
Mild	64 (36.16%)	389 (36.09%)	60 (53.10%)		
Moderate	32 (18.08%)	158 (14.66%)	10 (8.85%)		
Serious	0 (0.00%)	1 (0.09%)	0 (0.00%)		
Loss of interest, n (%)				10.621	.031
None	131 (74.01%)	798 (74.03%)	98 (86.73%)		
Mild	39 (22.03%)	221 (20.50%)	10 (8.85%)		
Moderate	7 (3.95%)	59 (5.47%)	5 (4.42%)		
Dizziness, n (%)				12.681	.013
None	121 (68.36%)	777 (72.08%)	94 (83.19%)		
Mild	47 (26.55%)	214 (19.85%)	13 (11.50%)		
Moderate	9 (5.08%)	87 (8.07%)	6 (5.31%)		

observed in the excellent protection subgroup, which seems inconsistent with what might have been expected and which requires further clarification.

3.4. Multivariate regression results

3.4.1. Sleep-related disorders.
The association of sleep disorders with the latent clusters is shown in Table 6. There was no association between sleep duration and the latent clusters, although consistent results from the poor behavior subgroup showed a >2-fold possibility of poorer self-rated sleep quality compared with the excellent sleep quality status as observed across the 8 models in relation to the excellent protection subgroup. Similar results were recorded concerning nightmare frequency, with a just >2-fold greater nightmare frequency at least once a week occurring in the poor behavior subgroup compared to those not experiencing nightmares, and, for the participants in the poor behavior subgroup with nightmare frequency of >3 times per week, the estimate incidence-rate ratios were 0.11, with these results being consistent from model 1 to model 8. The results showed a nearly 2-fold greater likelihood of sleep disorders in the poor awareness subgroup than in the excellent protection subgroup, which was consistent across the models. For other sleep disorders, insufficient evidence was found to determine any significant associations within the latent clusters.

3.4.2. Neurologic symptoms.
Relationships between the latent clusters and non-sleep disorder symptoms are shown in Table 7.

Although debility was significantly found in the poor behavior subgroup in Models 1 to 4, the association became insignificant after the potential confounding factors being controlled, which suggested that potential confounding factors could mediate/moderate the relationship. Similarly, an association was observed between both hypopsia and hypomnesis in relation to the poor behavior subgroup, with a 1.8-fold likelihood of an increase in the prevalence of risk compared to the excellent protection subgroup. However, for symptoms involving loss of interest and dizziness, the results demonstrated that participants in the poor behavior subgroup had a lower likelihood of prevalence, which was consistent across the models. This counterintuitive result requires further research to verify and explain it.

4. Discussion

Through using LCA, 3 distinct cluster subgroups among greenhouse farmers were identified. We found that the poor behavior subgroup had a greater likelihood of reporting neurologic symptoms than the poor awareness subgroup. Although there has been little previous research exploring the links between pesticide spray protection awareness and behavior among greenhouse farmers, we found in this study that poor protection behavior was associated with sleep disorders and neurologic symptoms, which is similar to results from previous studies showing that the frequency of pesticide use was positively associated with neurobehavioral and neurologic symptoms.[3,11]

Neurologic dysfunction has been defined as a major health hazard symptom in a previous study.[11] One longitudinal study has shown that chlorpyrifos exposure causes neurological symptoms.[18] Other studies have also found an association between specific pesticides and neurologic symptoms in Asia[19] and other developing countries.[20] However, measuring specific pesticide exposure does not necessarily reflect a farmer's actual exposure level in their daily work because pesticide exposure is a dynamic process that can be influenced through other unobserved confounding factors. Taking into consideration factors such as knowledge, practice, and attitudes regarding pesticides can help clarify findings on the effects of pesticide on health, as shown in a previous study involving a low-income country.[20] Exploring both the extent of awareness concerning pesticide use as well as behavior in relation to pesticide use is more likely to provide a more accurate reflection of farmers' actual exposure levels.

Pesticide spray practice and the corresponding level of protection reveal an important exposure pathway, with little or no protection increasing the possibility of pesticide exposure and negative effects on health.[21] Poor behavior in relation to pesticide use was found in our study to have an increased odds ratio of poor sleep quality and nightmare frequency; therefore, given that a negative relationship between lengthy working hours and workers' sleep quality has been found among agricultural workers[22] and that long-term organophosphorus exposure has been observed to negatively influence sleep quality among Chinese farmers;[23] our findings in conjunction with previous findings suggest that poor behavior concerning pesticide use is likely to increase the intensity levels of pesticide exposure, requiring improvements and reform in the provisions and regulations concerning protection equipment for farmers. Reduced sleep quality is associated with metabolic syndrome,[24] youth ischemic stroke,[25] and poorer health. A clear relationship between the level of protection awareness in relation to pesticide use and suffering from sleep disorders was identified in this study. Poor awareness affects the ability to take protective action and increases the possibility of greater pesticide exposure, with further negative health effects through increasing neurologic symptoms.

Apart from sleep disorders, the results obtained in this study concerning the poor behavior subgroup in relation to pesticide use showed that this subgroup had an increased likelihood of hypopsia and hypomnesis compared with the excellent protection subgroup. An average 1.8-fold odds ratio difference was detected. This was smaller than in a previous study assessing pesticide exposure.[11] This variation was possibly because our study focused on awareness and behavior in relation to pesticide use, which did not consider testing for pesticide residual effects within the body that might have influenced the effect intensity. Debility is one bodily adverse reaction to the effects of pesticide, which can involve inhibition of cholinesterase activity and negatively affect hematological, renal,, and hepatic indices,[26] as well as lead to butyrylcholinesterase inhibition.[27] The results of our study in relation to hypopsia were consistent with conclusions from a previous study,[27] and has been found that long-term exposure to pesticides showed disturbances in perceptive and visuospatial processing.[28] The likelihood of hypomnesis was also shown to be associated with poor behavior in relation to pesticide use. Previous studies have shown that lower scores in the recall of a logical story (involving the logical memory) could be related to pesticide exposure,[27] whereas experimental results have shown that there is memory impairment at the GABAA receptor level in rats under pesticide exposure,[29] and that memory interruption occurs in the spatial working memories of bees owing to pesticide exposure.[30] Further study is needed to clarify the relevant mechanisms in humans through clinical or experiment research. An interesting finding in this study was that loss of interest and dizziness were positively associated with poor behavior in relation to pesticide

Table 6

Multivariable results of the association between sleep disorder and awareness and behavior concerning pesticide use among the latent clusters.

Models	Sleep 1* (beta, 95% CI)	Sleep 2† (RRR, 95% CI; reference=excellent)			Sleep 3‡ (IRR, 95% CI)	Sleep 4§ (OR, 95% CI)	Sleep 5§ (OR, 95% CI)	Sleep 6† (RRR, 95% CI; reference=none)			Sleep 7† (RRR, 95% CI; reference=none)		
		Good	Worse	Much worse				<1/wk	1-2/wk	≥3/wk	<1/wk	1-2/wk	≥3/wk
Model 1	0.21 (−0.01 to 0.42)	0.96 (0.69 to 1.35)	0.62 (0.35 to 1.10)	0.43 (0.10 to 1.86)	1.00 (0.86 to 1.17)	1.00 (0.66 to 1.51)	1.01 (0.86 to 1.18)	0.97 (0.66 to 1.42)	0.99 (0.54 to 1.81)	1.36 (0.81 to 2.86)	2.12 (1.13 to 3.97)	0.61 (0.18 to 2.02)	2.24 (1.11 to 4.54)
	−0.09 (−0.35 to 0.18)	2.13 (1.39 to 3.26)	1.10 (0.55 to 2.23)	0.53 (0.07 to 4.01)	1.02 (0.84 to 1.23)	0.63 (0.35 to 1.12)	1.01 (0.84 to 1.22)	2.09 (1.40 to 3.14)	0.51 (0.18 to 1.43)	0.23 (0.06 to 0.97)	0.22 (0.03 to 1.59)	1.75 (0.72 to 4.28)	0.58 (0.14 to 2.47)
Model 2	0.15 (−0.07 to 0.38)	0.95 (0.67 to 1.35)	0.56 (0.30 to 1.03)	0.45 (0.10 to 1.98)	1.00 (0.85 to 1.18)	0.91 (0.58 to 1.41)	1.00 (0.85 to 1.17)	0.90 (0.59 to 1.39)	0.97 (0.52 to 1.78)	1.14 (0.65 to 1.98)	2.02 (1.07 to 3.83)	0.60 (0.18 to 2.03)	2.24 (1.04 to 4.79)
	−0.13 (−0.39 to 0.14)	2.15 (1.39 to 3.34)	1.23 (0.60 to 2.54)	0.63 (0.08 to 4.84)	1.02 (0.84 to 1.24)	0.69 (0.38 to 1.25)	1.02 (0.84 to 1.23)	2.24 (1.45 to 3.46)	0.53 (0.19 to 1.51)	0.11 (0.01 to 0.81)	0.22 (0.03 to 1.63)	1.78 (0.71 to 4.47)	0.35 (0.05 to 2.60)
Model 3	0.20 (−0.02 to 0.41)	0.97 (0.69 to 1.37)	0.63 (0.35 to 1.12)	0.44 (0.10 to 1.88)	1.00 (0.86 to 1.17)	1.03 (0.68 to 1.56)	1.01 (0.87 to 1.18)	0.98 (0.66 to 1.44)	1.00 (0.55 to 1.82)	1.37 (0.82 to 2.31)	2.11 (1.13 to 3.96)	0.64 (0.19 to 2.11)	2.24 (1.10 to 4.53)
	−0.10 (−0.36 to 0.17)	2.15 (1.40 to 3.31)	1.12 (0.55 to 2.27)	0.54 (0.07 to 4.13)	1.02 (0.84 to 1.23)	0.63 (0.35 to 1.12)	1.01 (0.84 to 1.22)	2.16 (1.43 to 3.24)	0.49 (0.17 to 1.40)	0.23 (0.05 to 0.94)	0.21 (0.03 to 1.57)	1.79 (0.72 to 4.41)	0.57 (0.13 to 2.40)
Model 4	0.20 (−0.01 to 0.42)	0.97 (0.69 to 1.36)	0.61 (0.34 to 1.10)	0.43 (0.10 to 1.84)	1.00 (0.86 to 1.17)	1.01 (0.67 to 1.52)	1.01 (0.86 to 1.18)	0.96 (0.65 to 1.41)	1.00 (0.55 to 1.82)	1.36 (0.81 to 2.29)	2.14 (1.14 to 4.00)	0.61 (0.18 to 2.01)	2.22 (1.10 to 4.51)
	−0.09 (−0.35 to 0.18)	2.15 (1.10 to 3.30)	1.10 (0.54 to 2.21)	0.52 (0.07 to 3.93)	1.02 (0.84 to 1.23)	0.63 (0.36 to 1.13)	1.01 (0.83 to 1.22)	2.06 (1.37 to 3.09)	0.51 (0.18 to 1.44)	0.23 (0.06 to 0.97)	0.22 (0.03 to 1.62)	1.73 (0.71 to 4.24)	0.57 (0.13 to 2.41)
Model 5	0.21 (−0.01 to 0.43)	0.90 (0.64 to 1.27)	0.60 (0.34 to 1.07)	0.39 (0.09 to 1.67)	1.00 (0.85 to 1.18)	0.97 (0.64 to 1.47)	1.01 (0.86 to 1.18)	0.90 (0.60 to 1.35)	0.97 (0.53 to 1.77)	1.32 (0.78 to 2.22)	2.09 (1.11 to 3.92)	0.59 (0.18 to 1.96)	2.26 (1.11 to 4.62)
	−0.04 (−0.32 to 0.23)	2.13 (1.37 to 3.31)	1.07 (0.51 to 2.23)	0.56 (0.07 to 4.29)	1.02 (0.84 to 1.24)	0.60 (0.33 to 1.09)	1.01 (0.84 to 1.23)	1.95 (1.29 to 2.97)	0.53 (0.19 to 1.49)	0.23 (0.06 to 0.98)	0.22 (0.03 to 1.65)	1.54 (0.58 to 4.06)	0.64 (0.15 to 2.73)
Model 6	0.22 (0.01 to 0.44)	0.95 (0.67 to 1.34)	0.63 (0.35 to 1.13)	0.43 (0.10 to 1.86)	1.00 (0.85 to 1.17)	0.93 (0.61 to 1.42)	1.00 (0.86 to 1.17)	0.95 (0.63 to 1.43)	0.87 (0.47 to 1.62)	1.38 (0.82 to 2.33)	2.06 (1.09 to 3.89)	0.61 (0.18 to 2.01)	2.25 (1.11 to 4.56)
	−0.11 (−0.38 to 0.15)	2.25 (1.45 to 3.49)	1.23 (0.60 to 2.50)	0.60 (0.08 to 4.58)	1.02 (0.84 to 1.23)	0.67 (0.37 to 1.20)	1.01 (0.84 to 1.22)	2.25 (1.46 to 3.47)	0.52 (0.18 to 1.48)	0.24 (0.06 to 1.02)	1.79 (0.73 to 4.40)	1.79 (0.73 to 4.40)	0.61 (0.14 to 2.60)
Model 7	0.17 (−0.05 to 0.38)	0.93 (0.66 to 1.30)	0.59 (0.33 to 1.06)	0.39 (0.09 to 1.69)	1.00 (0.85 to 1.17)	0.91 (0.60 to 1.38)	1.00 (0.85 to 1.16)	0.86 (0.58 to 1.28)	0.91 (0.50 to 1.68)	1.21 (0.72 to 2.05)	1.78 (0.94 to 3.37)	0.47 (0.14 to 1.55)	1.74 (0.85 to 3.57)
	−0.10 (−0.37 to 0.16)	2.09 (1.36 to 3.21)	1.08 (0.54 to 2.19)	0.51 (0.07 to 3.87)	1.02 (0.84 to 1.23)	0.61 (0.34 to 1.08)	1.00 (0.83 to 1.21)	2.01 (1.34 to 3.02)	0.49 (0.17 to 1.39)	0.22 (0.05 to 0.93)	0.20 (0.03 to 1.50)	1.63 (0.66 to 4.04)	0.54 (0.13 to 2.31)
Model 8	0.12 (−0.11 to 0.35)	0.85 (0.58 to 1.23)	0.52 (0.27 to 0.98)	0.38 (0.08 to 1.72)	1.00 (0.84 to 1.18)	0.83 (0.55 to 1.37)	1.00 (0.84 to 1.17)	0.73 (0.46 to 1.15)	0.84 (0.44 to 1.61)	1.03 (0.58 to 1.82)	1.72 (0.89 to 3.31)	0.53 (0.15 to 1.84)	2.02 (0.91 to 4.49)
	−0.13 (−0.40 to 0.14)	2.40 (1.50 to 3.84)	1.23 (0.55 to 2.71)	0.68 (0.08 to 5.47)	1.02 (0.83 to 1.25)	0.65 (0.35 to 1.22)	1.02 (0.83 to 1.24)	2.22 (1.37 to 3.58)	0.52 (0.18 to 1.52)	0.11 (0.01 to 0.80)	0.20 (0.03 to 1.49)	1.45 (0.51 to 4.12)	0.34 (0.04 to 2.62)

Note: the reference cluster was set as Cluster 2 in the different models (the first row shows results from Cluster 1 vs Cluster 2, the second row shows results Cluster 3 vs Cluster 2 in each model); and Cluster 1 refers to the poor awareness subgroup, Cluster 2 refers to the excellent protection subgroup, and Cluster 3 refers to the poor behavior subgroup.

Model 1 was an empty model that included latent cluster as an independent variable only; Model 2 adjusted according to family numbers, sex, ethnicity, age, education level, marital status, and the years of local residence; Model 3 adjusted for disease history diagnosed more than one year previously and in the recent year; Model 4 adjusted according to income level; Model 5 adjusted according to smoking status, alcohol consumption frequency, physical exercise, breakfast frequency; Model 6 adjusted for planting years, average planting area, and working days spent in the greenhouse; Model 7 adjusted for survey year; Model 8 adjusted for all covariates.

Sleep 1, sleep duration (h); Sleep 2, self-perceived sleep quality; Sleep 3, frequency of hypnotic drug use; Sleep 4, difficulty falling asleep; Sleep 5, sleep apnea; Sleep 6, nightmares; Sleep 7, suffering from a sleep disorder.

CI=confidence interval, IRR=incidence-rate ratios, OR=odds ratio, RRR=relative-risk ratios.

* Linear regression model.
† Multinomial logistic regression model.
‡ Poisson regression model.
§ Ordinal logistic regression model.

Table 7

Multivariable results of the association with neurologic symptoms and awareness and behavior concerning pesticide use among the latent clusters.

Models	NS1* (RRR, 95% CI; Reference=None)		NS2* (RRR, 95% CI; Reference=None)		NS3* (RRR, 95% CI; Reference=None)		NS4† (OR, 95% CI)	NS5† (OR, 95% CI)
	Mild	Moderate/serious	Mild	Moderate	Mild	Moderate/serious		
Model 1	1.18 (0.84–1.64)	0.95 (0.55–1.66)	0.86 (0.60–1.23)	1.25 (0.79–1.98)	1.08 (0.76–1.53)	1.32 (0.84–2.06)	0.98 (0.68–1.40)	1.12 (0.80–1.58)
	1.53 (1.02–2.29)	0.45 (0.18–1.16)	1.78 (1.19–2.64)	0.51 (0.22–1.23)	1.90 (1.26–2.87)	0.78 (0.38–1.58)	0.45 (0.25–0.78)	0.53 (0.32–0.88)
Model 2	1.22 (0.86–1.73)	0.96 (0.54–1.71)	0.86 (0.59–1.27)	1.07 (0.65–1.79)	1.09 (0.75–1.59)	1.36 (0.85–2.17)	0.89 (0.61–1.32)	1.02 (0.71–1.46)
	1.53 (1.01–2.33)	0.49 (0.19–1.26)	1.73 (1.13–2.64)	0.44 (0.17–1.13)	1.90 (1.24–2.92)	0.75 (0.35–1.60)	0.47 (0.27–0.84)	0.53 (0.31–0.90)
Model 3	1.19 (0.85–1.66)	0.96 (0.55–1.67)	0.87 (0.61–1.25)	1.27 (0.80–2.02)	1.09 (0.77–1.55)	1.34 (0.86–2.10)	0.99 (0.69–1.42)	1.14 (0.81–1.60)
	1.53 (1.02–2.30)	0.44 (0.17–1.14)	1.78 (1.19–2.67)	0.52 (0.22–1.24)	1.91 (1.27–2.90)	0.79 (0.39–1.61)	0.44 (0.25–0.78)	0.5 1(0.31–0.85)
Model 4	1.17 (0.84–1.64)	0.95 (0.55–1.65)	0.85 (0.59–1.22)	1.24 (0.78–1.97)	1.07 (0.75–1.52)	1.31 (0.84–2.04)	0.99 (0.69–1.41)	1.12 (0.80–1.58)
	1.50 (1.00–2.26)	0.45 (0.17–1.15)	1.74 (1.16–2.61)	0.5 1(0.21–1.21)	1.86 (1.23–2.82)	0.76 (0.37–1.54)	0.45 (0.26–0.79)	0.52 (0.31–0.87)
Model 5	1.12 (0.79–1.57)	0.96 (0.55–1.66)	0.81 (0.56–1.18)	1.25 (0.78–1.98)	1.02 (0.71–1.47)	1.33 (0.85–2.08)	1.01 (0.70–1.45)	1.11 (0.79–1.56)
	1.49 (0.99–2.26)	0.49 (0.19–1.26)	1.80 (1.19–2.72)	0.54 (0.23–1.29)	1.83 (1.20–2.79)	0.83 (0.41–1.70)	0.49 (0.28–0.87)	0.56 (0.33–0.94)
Model 6	1.21 (0.86–1.70)	0.97 (0.56–1.68)	0.89 (0.62–1.28)	1.22 (0.77–1.95)	1.08 (0.76–1.55)	1.35 (0.86–2.12)	0.96 (0.67–1.39)	1.15 (0.82–1.62)
	1.64 (1.08–2.48)	0.48 (0.19–1.25)	1.85 (1.23–2.79)	0.54 (0.23–1.29)	1.99 (1.31–3.02)	0.85 (0.42–1.74)	0.48 (0.27–0.84)	0.55 (0.33–0.92)
Model 7	1.07 (0.76–1.50)	0.80 (0.46–1.40)	0.86 (0.59–1.23)	1.07 (0.67–1.70)	1.03 (0.72–1.47)	1.04 (0.66–1.65)	0.86 (0.60–1.24)	1.04 (0.74–1.46)
	1.46 (0.97–2.20)	0.42 (0.16–1.09)	1.77 (1.18–2.65)	0.48 (0.20–1.15)	1.86 (1.23–2.81)	0.71 (0.35–1.46)	0.42 (0.24–0.74)	0.51 (0.31–0.85)
Model 8	1.03 (0.72–1.50)	0.83 (0.46–1.50)	0.78 (0.53–1.16)	0.93 (0.55–1.57)	0.96 (0.65–1.42)	1.14 (0.70–1.87)	0.84 (0.57–1.26)	0.99 (0.68–1.43)
	1.54 (0.98–2.40)	0.44 (0.16–1.18)	1.75 (1.12–2.73)	0.43 (0.16–1.13)	1.79 (1.15–2.80)	0.71 (0.32–1.55)	0.50 (0.27–0.90)	0.53 (0.31–0.92)

Note: the reference cluster was set as cluster 2 in the different models (the first row shows the results from Cluster 1 vs Cluster 2, the second row shows Cluster 3 vs Cluster 2 in each model); and Cluster 1 refers to the poor awareness subgroup, Cluster 2 refer to the excellent protection subgroup, and Cluster 3 refers to the poor behavior subgroup.

Model 1 is an empty model that was included as a latent cluster to be an independent variable only; Model 2 adjusted for the number of family members, sex, ethnicity, age, education level, marital status, and the years of local residence; Model 3 adjusted for disease history diagnosed >1 year previously and in the recent year; Model 4 adjusted for income level; Model 5 adjusted for smoking status, alcohol consumption frequency, physical exercise, breakfast frequency; Model 6 adjusted for planting years, average planting area, and working days spent in the greenhouse; Model 7 adjusted for the survey year; Model 8 adjusted for all covariates.

CI=confidence interval, NS1=debility, NS2=hypopsia, NS3=hypomnesis, NS4=loss of interest, NS5=dizziness, OR=odds ratio, RRR=relative-risk ratios.

* Multinomial logistic regression model.

† Ordinal logistic regression model.

use, which requires further study to determine more precisely what is involved here.

Overall, this study found that poor pesticide protection behavior was more likely to result in impairments to health than poor awareness of pesticide use, which we consider to be a major finding. The strength of this study was that it used LCA to divide farmers into different groups in relation to pesticide awareness and behavior via a person-centered method, which reduced the risk of misclassification and improved the accuracy of the analyses. Numerous predictors of pesticide protection awareness and behavior were used to classify the latent clusters as precisely as possible and 12 questions were used to reflect the neurologic symptoms more comprehensively. However, this study has some limitations. First, the cross-sectional study design had a limited opportunity to draw causal inferences. Second, all the variables in our study were collected through self-reporting, which leaded to some degree of information bias that might have affected our results. Third, as our results were derived from an observational study, potential mechanisms that might have explained our results could not be explored. Therefore, for further related research, clinical diagnoses and a cohort study design would be needed to explore the causal relationship more effectively.

5. Conclusions

Three distinct latent clusters in relation to awareness and behavior concerning pesticide use were determined, namely a poor awareness subgroup, an excellent protection subgroup, and a poor behavior subgroup, involving a sample of greenhouse farmers from outlying areas in Yinchuan in China. There was a greater association between participants in the poor behavior subgroup and adverse neurologic symptoms than among participants in the other subgroups. Sleep disorders, sleep quality, and nightmare frequency were negatively associated with poor behavior, as were hypopsia and hypomnesis. However, there was one clear association found between the levels of awareness concerning pesticide use and suffering from sleep disorders. These findings suggest that targeted interventions to help local greenhouse farmers improve their pesticide protection behavior are urgently needed. In the meantime, it is recommended that local farmers be provided with or encouraged to buy high-quality protective equipment. Finally, despite our results not confirming that awareness concerning the proper use of pesticides can be decisively linked with the onset of neurologic symptoms, we would still recommend that further education concerning pesticide protection is necessary.

Author contributions

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