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RESEARCH ARTICLE

Farmers' health risk and the use of personal protective equipment (PPE) during pesticide application

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Abstract

Personal protective equipment (PPE) is always considered the last and sometimes the most important safety shield against pesticides' hazards health risks. The spread of pests and low-quality pesticides, especially in developing countries, has increased health hazard potential among farmers. The present study aimed to assess farmers' health risks when using PPE (composite index) by exploring its most important predictive factors. A sample of 370 farmers in Ardabil province, Iran, was selected based on the multistage sampling method. The results reveal that most farmers use three types of PPE when applying pesticides. Based on their perception of pesticides' health risk, the number of PPE used differs. The highest health hazard in using PPE and the minimum perception of health risks caused by pesticides among farmers are related to the pesticides Paraquat and Chlorpyrifos. Also, the most important predictive factors of the composite index were found to be farm size, pesticides' health risk perception, previous experiences with harmful effects of chemical pesticides on health (especially among large-scale farmers), training courses, and ability to afford PPE-related costs, respectively. Accordingly, farmers' safety and health programs in the region should focus on reducing or replacing the mentioned high-risk pesticides. Reducing government subsidies for high-risk pesticides, establishing government subsidies for farmers' PPE, providing extension training (especially for small-scale farmers), and receiving ongoing training feedback to improve farmers' health risk perception of pesticides and the need to use PPE will effectively reduce farmers' health risks.

Keywords Personal protection equipment · Potato farmers · Pesticides · Health risk

Introduction

During the last five decades, the application of pesticides became a crucial part of agricultural activities to increase food production in developing countries. However, the high spread of crop pests, the prevalence of low-quality pesticides, and the tendency towards obtaining more profit have led to a significant increase of chemical pesticides use by farmers (Rezaei et al. 2020). Statistics on health risks and farmworkers and farmers' poisoning in developing countries reveal an increasing trend resulting from the lack of safety behavior among farmers (especially the use of personal protection equipment, or PPE) in parallel with the increase in pesticides use (Sharifzadeh et al. 2018; Okoffo et al. 2016; Akter et al. 2018; Yarpuz-Bozdogan 2018). PPE includes the instruments that can be used by farmers or farmworkers against safety or health hazards (confronting dangerous situations, and dangerous or poisoning materials), and they can be different based on the risk type (Garrigou et al. 2020; Joko et al. 2020).

Recently, an increasing rate of chemical pesticide use has been reported in many parts of Iran, due to a rise in pest outbreaks, such as the outbreak of rice pests in the north of Iran and the outbreak of potato pests in Ardabil Province, Northwestern Iran (Rezaei et al. 2020; Sharifzadeh et al. 2018; Bagheri et al. 2019). Potato is the most important crop in Ardabil Province, but it is susceptible to the invasion of

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several pests as Colorado beetle (*Leptinotarsa decemlineata*) and downy mildew (Agri-Jihad Organization of Ardabil Province 2019; Tajmiri et al. 2017; Asgar et al. 2017). In addition, the prevalence of the use of low-quality pesticides and the increasing resistance of some pests (like increasing resistance of potato pests to Metribuzin) has further increased the application of pesticides in Iran (Diyanat et al. 2019).

Prevailing solutions used by farmers for pest control can lead to a high use of pesticides or the use of pesticides with higher toxicity (Joko et al. 2020; Bagheri et al. 2019). On average, about 14,000 tons of different types of chemical pesticides are used annually in Iran. Based on the World Health Organization (WHO) pesticides' toxicity classification, about half of pesticides used in Iran are classified at average (II) or a very dangerous (Ia) toxicity level (Morteza et al. 2017). Obviously, the increasing use of chemical pesticides and their growingly dangerous threat to health have made it necessary to explore the use of PPE by farmers (Sharifzadeh et al. 2018; Joko et al. 2020). The use of PPE is usually considered the last safety shield and sometimes the most important mechanism used by farmers to reduce chemical pesticides' hazards. However, since farmers in Iran are mostly smallholders, the preparation and use of PPE may not seem important or cost effective. This will increase farmers' health hazard risks (Sharifzadeh et al. 2018).

In addition, the lack of awareness and improper perception about pesticide's hazard level influence farmers' safety behavior and PPE level use (Joko et al. 2020; Rezaei et al. 2020). In most similar studies, farmers' use of PPE has been studied mostly as a safety behavior, with no consideration of health hazard levels of the different types of pesticides. Also, PPE use has been assumed to be the same for all types of pesticides. In other words, there is an inaccurate assumption that farmers always use a fixed number of PPE when applying any type of pesticide and do not differentiate between the various types of pesticides. Moreover, some factors such as the effect of farmers' perceptions regarding pesticides' toxicity level on PPE use are ignored, and specifically, the most dangerous pesticides for farmers' health, based on the application level of PPE, are not identified. Further, in previous studies, no accurate index has been proposed to assess farmers' health risk related to the application level of PPE. Given this existing scientific gap, the present study aims to specify the most important predictive factors of farmers' health risk levels in using PPE, during pesticide application, and more precisely to assess health risk levels among farmers in using PPE, separately for each pesticide. In this regard, it is necessary to identify prevailing pesticides, to identify farmers PPE use for each pesticide. Farmers' health risk index can be determined based on the ratio of the use of recommended PPE for each pesticide (based on the label and brochure of pesticides) to the number of PPE used by farmers and the degree of toxicity of pesticides. Various studies have emphasized the effect of farmers' perception of pesticides' health risk on their safety behaviors (Joko et al. 2020; Sharifzadeh et al. 2018). Therefore, it is important to study farmers' perceptions regarding pesticides' health hazards, and their impact on the use of PPE, and finally, the most important variables predicting the health risk of farmers in the use of PPE are discussed. Hence, the research' objectives can be summarized as below:

1. Specifying various types of prevailing pesticides and application-level of PPE by farmers separately for each pesticide;
2. Assessing farmers' health risk with respect to the use of PPE (composite index (CI)) and specifying the most dangerous pesticides;
3. Studying farmers' perception regarding pesticides' health hazards and their effect on health risk index of farmers in using PPE; and
4. Determining the most important predictive factors for health risk index among farmers in using PPE.

Research background

Due to the increasing use of pesticides, especially those with a higher level of toxicity; it is important more than ever to use PPE at a wide scale. However, many farmers, especially in developing countries, do not use PPE sufficiently and appropriately when applying chemical pesticides (Joko et al. 2020; Ndayambaje et al. 2019; Moradhaseli et al. 2017; Bakhsh et al. 2017; Okoffo et al. 2016). Among farmers who use PPE, highly applied equipment usually includes hats, long-sleeve clothes, and/or boots (Joko et al. 2020; Ndayambaje et al. 2019; Damalas and Abdollahzadeh 2016). However, gloves, goggles, and respirators are usually the least used equipment among farmers (Russell-Green et al. 2020; Joko et al. 2020; Damalas and Abdollahzadeh 2016). Identifying the predictive and sometimes encouraging factors of farmers' use of PPE can play an important role in maintaining their safety (Sharifzadeh et al. 2018).

In general, variables such as age, agricultural experience, education level, farm size, income level, and ability to afford PPE-related costs are the determining factors of PPE adoption and use (Kearney et al. 2015; Bakhsh et al. 2017; Moradhaseli et al. 2017; Damalas and Abdollahzadeh 2016; Okoffo et al. 2016; Russell-Green et al. 2020). For example, Okoffo et al. (2016) and Ndayambaje et al. (2019) have highly underlined the effect of farm size on PPE use. Farmers' education level is also directly related to the use of PPE (Bakhsh et al. 2017; Okoffo et al. 2016). However, in the research of Ndayambaje et al. (2019), the role of education has not been found to be effective in the use of PPE. Moreover, pesticides' health risk perception and previous experiences related to chemical pesticides effects on health play an effective role in the greater use of PPE (Bakhsh et al. 2017; Russell-Green et al. 2020). The risk perception is a personal mental evaluation of a practical program or behavior upon which an individual reaches an intellectual consensus, i.e., what consequences will be probably expected by him against performing a program or behavior (Wilson et al. 2019; Chionis and Karanikas 2018; Sjoberg et al. 2004).

In this respect, according to Damalas and Abdollahzadeh (2016), the correct perception of pesticides' health risk has a positive and significant effect on the use of PPE. Also, the increased vulnerability of farmers to pesticides poisoning depends on their proper perception of how risky the chemical pesticides are, as well as on their desirable knowledge. In numerous studies, the emphasis has been put on the importance of previous experiences of chemical pesticides harmful effects of on health, safety behavior, and application level of PPE (Ndayambaje et al. 2019; Russell-Green et al. 2020; Afshari et al. 2018; Damalas and Abdollahzadeh 2016). Probably, the most important stage of chemical pesticides use where the use of PPE is more important than other stages is during chemical pesticide application or spraying (Sharifzadeh et al. 2018). According to Joko et al. (2020), Franklin et al. (2015), and Kearney et al. (2015), some factors such as ease of PPE use and inconvenience in spraying pesticides are considered important obstacles to PPE use by farmers. Moradhaseli et al. (2017) and Okoffo et al. (2016) report that behavioral habits such as eating, drinking, or smoking during pesticide spraying are exhibited by most farmers, and these behavioral habits are effective in PPE use. Based on our research objectives, four main hypotheses are presented in the study: (H1) farmers use a number of fixed PPE when using all pesticides; (H2) farmers' perception about the health risk of pesticides are consistent with the degree of toxicity of pesticides; (H3) the use of farmers' PPE is consistent with farmers' perception about the health risk of pesticides; and (H4) farmers' health risk is higher when using PPE for pesticides with higher toxicity.

Methodology

Study area

Ardabil is one of the thirty-one provinces of Iran. Located in the northwest part of the country (lat. 27° N., long. 30° E.), it has an area of about 17,800 km^2 and a cold semiarid climate. Due to its favorable climate and fertile land, Ardabil is one of the main agricultural region of Iran, producing a variety of products such as wheat, tomatoes and oilseeds. Potato (*Solanum tuberosum* L.) is the single most important agricultural commodity in the province of Ardabil. About 21.340 ha of the agricultural lands in the province are under the cultivation of potato, and it is the second-leading potatoes production region in Iran. Amid growing worries over food shortages, Iran has increased its potato production by more than 20% since 2009. Since 2015, it has steadily produced 5 million tons of potatoes, more than 17% of which, 850000 tons, is produced in Ardabil province. Problems with specific diseases or pests such as cut worms or infections with fungi, viruses, or bacteria are common in Ardabil province (Schripsema and Meijer 2017). Consequently, applying pesticides is crucial for potato production in the province.

Sample selection

Of all potato farmers in Ardabil province as the statistical population (N = 4876), the sample size was specified to be 370 individuals based on Bartlett et al. (2001) table who were taken by the multi-stage sampling method. So, at the first stage, the farmers who were cultivating potato in Ardabil and residing in three counties with the highest area of land under potato cultivation (i.e., Ardabil, Namin, and Nir) were considered. Then, proportionate to farmers' population in each county, 16 villages were selected randomly (eight at Ardabil, five at Namin, and three at Nir). Finally, 370 farmers were randomly taken from the selected villages proportionate to the population of potato growers. The final sample was composed of 193 farmers from Ardabil, 104 from Namin, and 73 from Nir. After referring to the target villages, respondents were randomly selected from the farmers cultivating potato, and data were collected. It should be noted that only farmers who used or participate in the process of using pesticides on the farm, were studied in this research.

Survey instrument

The study is based on a structured questionnaire composed of three sections. The first section included farmers' demographic characteristics such as age, education level (years and rank), average annual income (million Iranian Rials), years of experience, and farm size (hectares). The second section included items related to potato-related pesticides use: pesticides used, PPE used, number of sprays per planting period, and record of participating in training courses about pesticide application. The third section collected data on health risk index of farmers in PPE use: health risk perception of pesticides, ease of PPE use, previous experiences with harmful effects of chemical pesticides on health, ability to afford PPE-related costs, and behavioral habits, e.g., eating, drinking, and smoking during pesticide spraying.

The details of the measurement of the main research variables are presented in Table 1. Data were collected through in-depth interviews with farmers and the checklist method. The content validity of the questionnaire was verified by a panel of faculty members, experts of

Table 1 Summary of the effective variables in health risk of farmers utilizing PPE

The main study variables	Number of items	Explanation
Age (years)	1	Open-ended question: age of each potato farmer (years)
Farming experience (years)	1	Open-ended question: farmers' experience in potato cultivation (years)
Education level (years and rank)	2	Open-ended question: number of years of formal education and level.
Annual farm income (million IRR[1])	1	Open-ended question: average annual income from agricultural activities in million IRR.
Farm size (ha)	1	Open-ended question: total area of farmland owned by the farmer in hectares.
Health risk perception of pesticides	8	For each of the prevailing potato pesticides (8 items), farmers' perception about the level of toxicity and hazard of pesticides was asked. Items were presented in several categories (based on toxicity degree specified by WHO (2010)): 1 = Unlikely to present an acute hazard (U), 2 = Slightly hazardous (III), 3 = Moderately hazardous (II), 4= Highly hazardous (Ib), and 5= Extremely hazardous (Ia)). Then, 1 and 0 were considered for every right and wrong answer, respectively, and the scores were summed up.
Ease of PPE use	1	Two-way question (0: no, 1: yes): Can difficulties to use PPE could be considered as a preventive factor in its use during pesticide application?
Previous experiences with the harmful effects of chemical pesticides on health	1	Open-ended question: How many times have you had serious previous experiences with the harmful effects of chemical pesticides on health?
Record of participating in training courses related to pesticides	1	Open-ended question: How many hours have you had participated in training courses related to chemical pesticides?
Number of sprays	8	For each of the prevalent pesticides (8 items), the number of sprays each pesticide in each cultivation period was asked. Then, the number of pesticide sprays was summed up.
Ability to afford PPE-related costs	8	For each of the necessary PPE (6 items), farmers' ability to afford PPE-related costs in every cultivation period was asked. Items were presented in two categories (0: no, 1: yes). Then, the points were summed up.
Behavioral habits during spraying (eating, drinking, and smoking)	1	Two-way question (0: mostly no, 1: mostly yes): Do you have a habit of eating, drinking or smoking while spraying?

[1] 1 US dollar≈150,000 Iranian Rials (IRR)

the Healthcare Center of Ardabil County and Agricultural Jihad Organization of the province, who's complementary and corrective views were applied at several stages. The reliability of the research instrument was estimated by Cronbach's alpha for those variables having a measurement scale, and showing a desirable reliability level (higher than 0.7).

Data analysis

The data was analyzed in descriptive and inferential phases. The descriptive phase used frequency, percentage, mean, and standard deviation. The inferential phase used correlation coefficients and the decision tree model based on the structural equations model. Also, to determine the health risk of each farmer, the CI was calculated through the following detailed stages.

Measurement of the health risk of farmers in PPE use: calculating CI

The checklist method was used during data collection to increase measurement precision for the calculation of CI (farmers' health risk in using PPE) and to verify the correctness of data collected from the questionnaire. The checklist was composed of a list of measurement factors, specifications, aspects, components, and criteria used for more accurate evaluation and sometimes verification in the practical field. It requires the direct presence of researchers through observation and review in the research area (Scriven 2007; Bagnara et al. 2019; Najafi Saleh et al. 2018). In the checklist questionnaire, a list of two-category items (1 = yes; 0 = no), including the name of different types of pesticides and PPE used by farmers, was formulated, and, the questionnaires were filled out in the presence of the research team at farms. Finally, after completing the checklist three times in different pesticide application periods, the mean value of the answers was used to calculate CI. In general, the measurement stages of each CI included the followings:

Step 1: Normalizing the measurement indicators to determine the CI

To estimate the CI, it is necessary to convert the values of all measurement indicators to one standard measurement unit. This step is used to resolve scale differences of the measurement indicators so that it will be possible to sum up the measurement indicators for the calculation of CI (Londoño Pineda et al. 2019; Hahn et al. 2009). When indicators have different measurement scales, this step is used to unify the units of measurement. Normalization will be obtained based on the real values of each indicator and minimum and maximum threshold values (Keshavarz et al. 2017; Serna et al. 2015; Sepúlveda 2008). In this study, because the scales of the measurement indicators (values of different types of pesticides) were the same, this step was ignored.

Step 2: Determining the weight for each measurement indicator

Weights are basically used to measure the severity or importance of the effect imposed by each measurement indicator to determine the CI (Londoño Pineda et al. 2019). Different statistical methods, such as the analytic hierarchy process and the data envelopment analysis (DEA), are available to determine the weights of indicators (Panda et al. 2016; Keshavarz et al. 2017). But, based on the research purpose, a more accurate and realistic basis can be used to determine the weight of each indicator (OECD 2008). Considering the main purpose of the present study, the best basis to assign weights to the measurement indicators and to study health risk levels during pesticide application was the toxicity level. Based on the pesticide toxicity classification provided by the World Health Organization (WHO 2010), the weight coefficients of pesticides and their proportion to health risk were determined in the range of 1 to 5 (1 = unlikely to present an acute hazard (U); 2 = slightly hazardous (III); 3 = moderately hazardous (II); 4 = highly hazardous (Ib); and 5 = extremely hazardous (Ia)) (Cornell University 2019; Kniss and Coburn 2015; Deihimfard et al. 2007; Kovach et al. 1992; Levitan et al. 1995; Gustafson 1989).

Step 3: Linearly aggregating the measurement indicators

At this step, the CI (the health risk of farmers in the use of PPE) for each farmer was obtained by summing up the measurement indicators (multiplied by their weight coefficients). The steps for the calculation of the CI were as follows:

$$CI_f = \sum(Ii \cdot W_i) = \sum\left(\frac{X'_i}{Xi} \cdot W_i\right) = \left(\frac{X'_1}{X1} \cdot W_1\right) + \left(\frac{X'_2}{X2} \cdot W_2\right) + \left(\frac{X'_3}{X3} \cdot W_3\right) + \left(\frac{X'_4}{X4} \cdot W_4\right) + \left(\frac{X'_5}{X5} \cdot W_5\right) + \ldots$$

CI_f Composite index: the amount of health risk index of farmers in use of PPE and f=1,2, 3…,370.

I Ratio of the number of recommended PPE to PPE used by farmer for each pesticide and i=1,2, 3…,8.

X'_i The number of recommended PPE for each pesticide (according to pesticide labels or brochures) and i= 1,2,3…,8.

Xi The number of PPE used by farmer for each pesticide and i=1,2, 3…,8.

W_i Indicators weight based on WHO toxicity classification of pesticide and i= 1,2, 3…,8.

Farmers can be divided into three groups based on the health risk index in the use of PPE, including low (1–33% of CI), medium (34–67% of CI), and high health risk (68–100% of CI) (Damalas and Khan 2016).

Types of pesticides and PPE used by farmers in the research area

In this study, the prevailing pesticides used by potato farmers in the survey areas included four herbicides (Paraquat, Metribuzin, Glyphosate, and Trifluralin), three insecticides (Imidacloprid, Diazinon and Chlorpyrifos), and one fungicide (Chlorothalonil). The list of the PPE being emphasized to be used during chemical pesticide application was prepared based on the pesticide labels and/or brochures related to pesticides (Material Safety Data Sheets). Labels and brochures of the pesticides introduce minimum PPE usage necessary for the pesticide application (Damalas and Abdollahzadeh 2016). Considering precise study of all labels and brochures of pesticides used by farmers, at least six PPE pieces including coverall (or long-sleeve shirt and long pants), rubber boots (or shoes plus socks), resistant hat, goggles (protective eyewear), resistant gloves, and filter mask (or respirator) should be used when applying paraquat, chlorothalonil, diazinon, and chlorpyrifos; and for metribuzin, imidacloprid, glyphosate, and trifluralin, at least five PPE items should be used including coverall (or long-sleeve shirt and long pants), rubber boots (or shoes plus socks), goggles (protective eyewear), resistant gloves, and filter mask (or respirator).

Results

Demographic characteristics of respondents

According to Table 2, the average age of the respondents was 45.519 years with the highest frequency of farmers in the age range of 50–60 years (24.9%). Also, their education level was on average 10.17 years. Most respondents (39.5%) had a senior high school level of education. Most respondent farmers

Table 2 The sociodemographic information of the respondent

Variables	Frequency	Percentage	Mean	SD
Age (years)			45.519	1.437
Less than 30	56	15.1		
30–40	83	22.4		
40–50	80	21.6		
50–60	92	24.9		
More than 60	59	15.9		
Farming experience (years)			21.710	2.127
Less than 10	97	26.2		
10–25	130	35.1		
25–40	101	27.3		
More than 40	42	11.4		
Education level			10.17	4.79
Illiterate	24	6.5		
Elementary school	41	11.1		
Junior high school	81	21.9		
Senior high school	146	39.5		
Academic degree	78	21.1		
Farm size			4.936	4.112
Less than 3	142	38.4		
3–6	107	28.9		
6–9	55	14.9		
9–12	44	11.9		
More than 12	22	5.9		
Annual farm income (million IRR[1])			233.36	11.612
Less than 150	73	19.7		
150–250	196	53.0		
250–350	52	14.1		
350–450	32	8.6		
More than 450	17	4.6		

[1] 1 US dollar≈150,000 Iranian Rials (IRR)

(35.1%) had 10 to 25 years of agricultural experience with an average of 21.71 years. More than half of the respondents had an annual agricultural income of 150–250 million IRR (53.0%) and a farm size of less than 3 ha (38.4%).

Health risk index of farmers in the use of PPE

According to Table 3, farmers use different PPE when using different pesticides. Concerning all pesticides, the number of PPE used by the farmers is fewer than the recommended number. Considering the ratio of the number of PPE used by farmers to the number of recommended equipment pieces, it can be concluded that among the studied pesticides, most farmers used PPE for imidacloprid (0.655) and glyphosate (0.654). But, for chlorpyrifos (0.450) and paraquat (0.484), they used the least number of PPE pieces. Overall, according to Fig. 1, the highest health risk index in using PPE was related to chlorpyrifos (6.668) and paraquat (6.201), whereas the lowest value was related to trifluralin (1.586) and chlorothalonil (1.856). It should be noted that the highly applied PPE pieces among farmers, based on frequency, were boots (87.3%), hats (77.6%), and gloves (62.2%), respectively. Respirators and safety goggles were the last priorities among farmers. Also, 76.2% of the farmers used 3 or fewer PPE pieces when applying pesticides.

Health risk perception of pesticides among farmers

According to Fig. 2, the minimum health risk perception by farmers was related to paraquat (25.4% of the respondents) and chlorpyrifos (36.5%), and the maximum was related to Imidacloprid (50.3%) and metribuzin (49.2%). Based on other findings, the health risk perception of pesticides was negatively and significantly ($r = -0.588$, $p < 0.01$) correlated to the

Table 3 A summary of the results related to farmers; health risk index in using PPE

Factor	Applied pesticides (X)	Number of PPE pieces used (X'i)	Number of recommended PPE pieces (Xi)	Ratio of PPE used to recommended PPE	Ratio of recommended PPE to PPE used	Indicators weight (Wi)	Average health risk index
Use of PPE	1. Paraquat	2.903	6	0.484	2.067	II=3	6.201
	2.Metribuzin	2.746	5	0.549	1.821	II=3	5.463
	3.Chlorothalonil	3.232	6	0.539	1.856	U=1	1.856
	4.Imidacloprid	3.276	5	0.655	1.526	II=3	4.578
	5. Diazinon	3.343	6	0.557	1.795	II=3	5.384
	6. Chlorpyrifos[a]	2.699	6	0.450	2.223	II=3	6.668
	7.Glyphosate[b]	3.272	5	0.654	1.528	III=2	3.056
	8.Trifluralin[c]	3.152	5	0.630	1.586	U=1	1.586
Used PPE of farmers							
1. Boots (87.3%); 2. hat (77.6%); 3. gloves (62.2%); 4. coverall (27.8%); 5. goggles (21.4%); 6. filter mask (13.8%)							

[a,b,c] It is calculated based on the number of farmers using the pesticide

health risk index of farmers in the use of PPE, but it was positively and significantly correlated to the number of PPE pieces used ($r = 0.492$, $p < 0.01$). That is, the higher the health risk perception level of the farmers regarding potato pesticides, the lower the health risk level in the use of PPE would be, and the higher the number of PPE pieces used by farmers would be.

The results of the decision tree model

Primarily, according to the grouping of the farmers in terms of CI, they were divided into three groups of low (34.1%), medium (26.5%), and high (39.5%) health risk groups. The following 12 variables were included into the model: age (year), farming experience (year), education level (year), average annual income (million IRR), farm size (hectare), health risk perception of pesticides, ease of PPE use, previous experiences with harmful effects of chemical pesticides on health, the record of attending in training courses (hour), ability to afford PPE-related costs, and behavioral habits during spraying (eating, drinking, and smoking). According to Fig. 3, the CRT decision tree model could account for a significant part of the variability of the health risk level in the use of PPE among farmers (70.3%). Also, the model's estimated value (0.297) obtained was acceptable. Among the variables included, those such as farm size, health risk perception of pesticides, previous experiences with harmful effects of chemical pesticides on health, the record of attending in training courses, and ability to afford PPE-related costs had a decisive role in predicting the amount of health risk of farmers in the use of PPE.

According to the findings, the first factor that is influential on the health risk index of the farmers was found to be farm size (improvement level equal to 0.101). Also, the farmers with a similar farm size of lower than 5.75 ha (67.3% of the total respondents) were more exposed to health risk in the use of PPE out of which 50.2% were exposed to a high level of health risk (node 1). Among the farmers with a farm size of > 5.75 ha (32.7% of the total respondents), only 17.4% were at a high level of health risk, and 71.1% were exposed to a low level of health risk (node 2). For farmers categorized as members of node 1, the

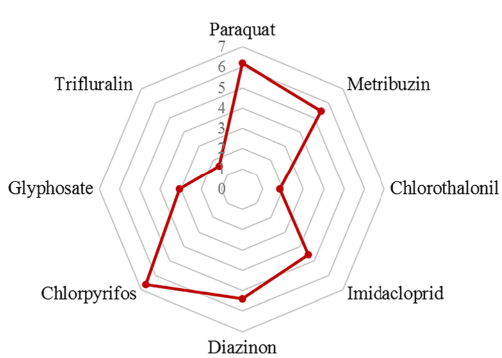

Fig. 1 The average health risk of farmers in the use of PPE

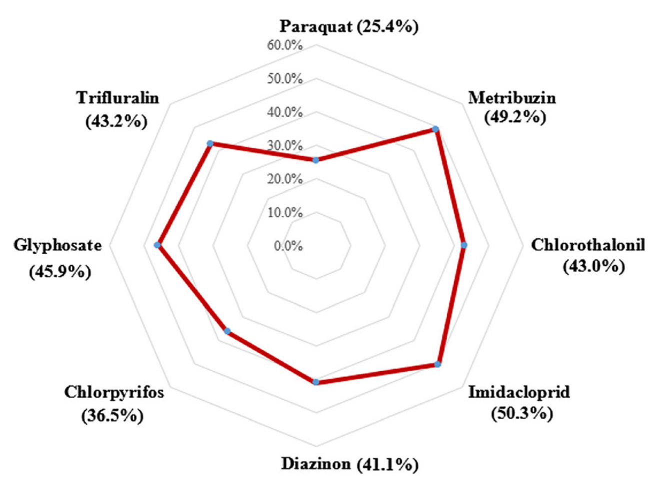

Fig. 2 Frequency distribution of health hazard perception among farmers

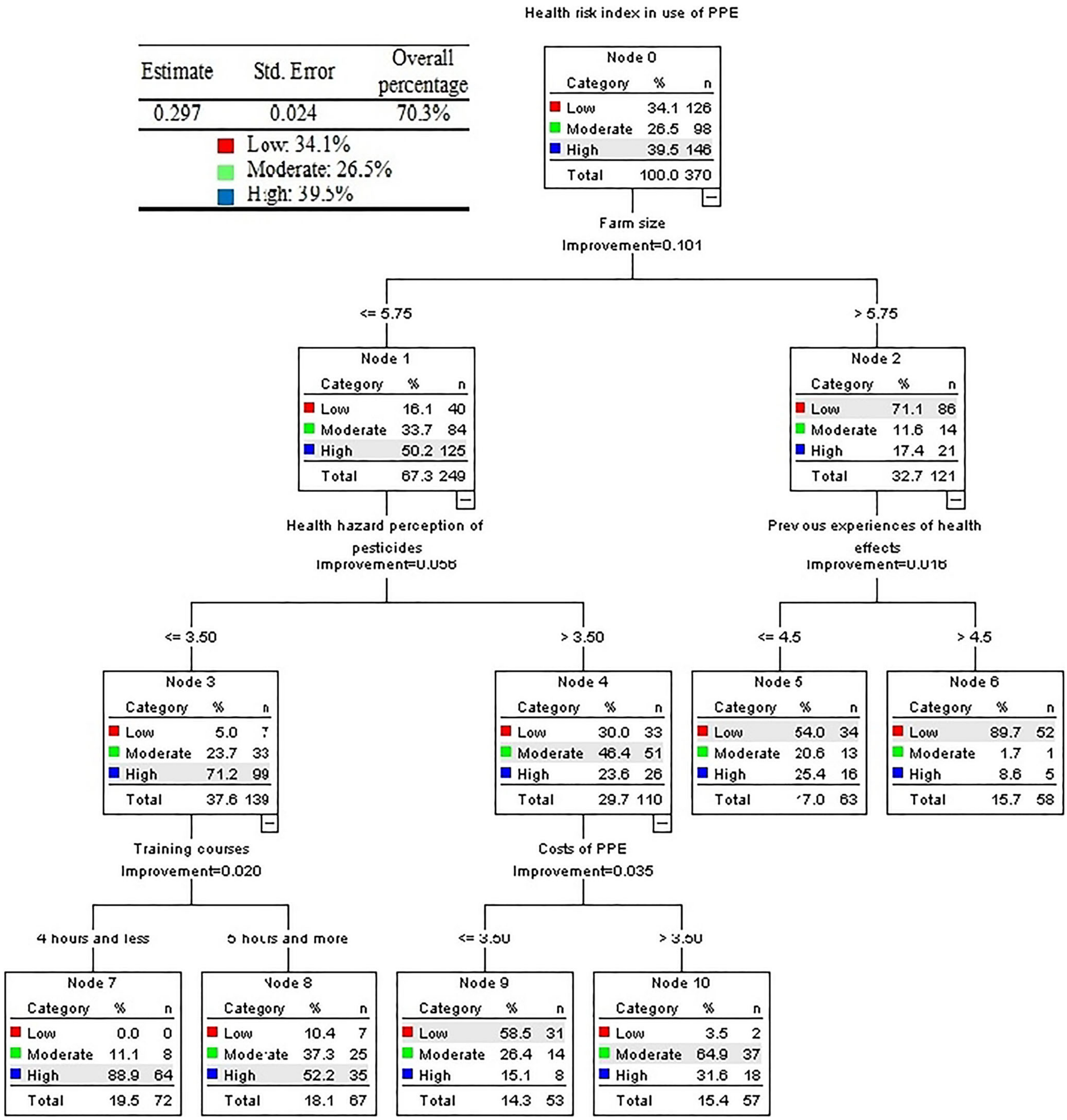

Fig. 3 Determinants of farmers' health risk index (CI) in the use of PPE

variable of health risk perception of pesticides was an important predictor of health risk index in the use of PPE. In this group, farmers who had a correct perception of the health hazards of more than 3 pesticides (node 4) were at a lower risk of health; that is, only 23.6% of them were at a high level of health risk.

For farmers categorized as members of node 2, previous experiences with the harmful effects of chemical pesticides on health were the only important predictor of the health risk index in the use of PPE (nodes 5 and 6). In this group, the majority of farmers who had previous experiences with the harmful effects of chemical pesticides (node 6) were at a lower level of health risk.

Also, among the members of node 3, the farmers who had records of attending in training courses for 4 h or more (node 8) were less exposed to health risk as compared to those with a record of 5 h or less (node 7) of attending in training courses. Moreover, among the members of node 4, the farmers who could afford the costs of only 3 pieces or fewer PPE (node 9) were more exposed to health risk in the use of PPE when compared to the other members of the group (node 10).

Results of research hypotheses

The results showed that although farmers do not use a fixed number of PPE when using all pesticides, the use of pesticides with a higher degree of toxicity has not necessarily led to the use of more PPE. Farmers use different types of PPE based on their perception of pesticides health risk. Also, farmers' perceptions of pesticides health risk do not match the degree of toxicity of the pesticides. Overall, farmers do not necessarily have a higher health risk when using PPE for higher toxicity pesticides. Therefore, H1, H2, and H4 hypotheses have not been confirmed by the research results. However, H3 hypothesis is confirmed by the research results.

Discussion

The study aimed to assess farmers' health risk regarding PPE use and to outline the most important predictive factors for health risk index among farmers in using PPE. Therefore, one of the limitations of the study was its constraints at the stage of pesticide application or spray. In other words, the health risk index assessment was not performed for the use of PPE in other stages of working with pesticides (including the stages of purchase and storage, preparation, and postapplication). Further, only farmers who were involved or participated in the pesticide application process on their farm were considered in this study. According to the findings, a few PPE pieces are used by most farmers. Consistent with the results obtained by Damalas and Abdollahzadeh (2016), Joko et al. (2020), and Ndayambaje et al. (2019), highly applied PPE pieces among potato farmers were boots and hats; while, the least used PPE pieces were respirators (or filter masks) and safety goggles.

Also, the highest health risk index related to PPE use and the lowest health risk perception among the farmers were related to chlorpyrifos and paraquat, respectively. So, it is recommended to prioritize these pesticides in training courses held for farmers on safety and in the development of alternative programs for chemical pesticides in the studied area. Also, the use of mass media and promotional brochures to introduce the hazards of pesticides mentioned and the need to use PPE when applying these pesticides can improve the safety and health of the farmers in the region.

According to the findings and consistent with Sharifzadeh et al. (2018), Okoffo et al. (2016), and Ndayambaje et al. (2019), farm size is one of the most important predictors of farmers' health risk in the use of PPE. It seems that since the variable of ability to afford PPE-related costs is also an effective factor of health risk index among small-scale farmers, these farmers will not consider the use of all PPE pieces cost effective. An appropriate management mechanism for smallholders whose farms are close to each other is to encourage them to be unified in safe pesticide application activities. Farmers can take turns spraying several farms side by side but with complete PPE.

Based on the findings and in line with the results obtained by Russell-Green et al. (2020), Joko et al. (2020), Ndayambaje et al. (2019), and Damalas and Abdollahzadeh (2016), another important factor related to farmers' health risk, especially among smallholders, is their perception of pesticides' hazards and their record of participating in training courses. Recognizing farmers' perception of how hazardous the pesticides relies on their educational feedback provided by agricultural extension agents. Also, holding training courses is effective in improving their perception of hazardous pesticides. Of course, farmers' knowledge improvement would not necessarily lead to the optimization of safety behavior in the use of pesticides, and it is necessary to conduct a thorough assessment of farmers' perception of the health risk of pesticides (Okoffo et al. 2016). Among large-scale farmers, the only predicting factor of farmers' health risk was previous experiences with the harmful effects of chemical pesticides on health (Ndayambaje et al. 2019; Russell-Green et al. 2020; Afshari et al. 2018; Damalas and Abdollahzadeh 2016). The farmers with previous experiences with the harmful effects of chemical pesticides on health are more sensitive and concerned about the use of PPE compared to other farmers. Farmers in this group spend a longer time on pesticide applications because they have larger farms. Under such circumstances, due to insufficient use of PPE, health complications will occur faster for them than for small-scale farmers, and corrective measures for their safety behavior will be more dependent on their previous health-related experiences. Also, the experience of paying different relevant costs such as treatment costs, losing leisure time, and health level are among important preventive factors in paying no attention to the use of PPE.

Conclusion

The results indicate the potential for a high health risk for farmers in the use of PPE when using pesticides. Therefore, the priority of farmers' safety and health programs in the region should focus on reducing or replacing high-risk pesticides. In this regard, we can mention the reduction of government subsidies for these pesticides. Although farmers may use some PPE items (e.g., boots and hats) for all pesticides, a better understanding of the health hazard of any pesticide will significantly increase the number of PPE items used by them. Improving farmers' perception regarding pesticides' health hazards requires relying on farmers' lifelong training about pesticides and paying attention to ongoing training feedback by agricultural extension agents. Although increasing knowledge can be effective in improving farmers' perceptions, regardless of farmers' perceived perceptions, promoting safety behavior and farmers' health risk in using pesticides will not have acceptable growth (Okoffo et al. 2016). Most potato farmers in Iran are small-scale, so the cost-benefit ratio of using PPE may not be acceptable to them. Clearly, providing government support subsidies for some PPE and facilitating access to PPEs among small-scale farmers can reduce the negative impact of PPE costs on the nonuse of PPE.

Authors' contributions M.S conducted the survey, gathered data, and analyzed data; MS.A. conceived the idea, planned the research, interpreted data, and wrote the article. All authors approved the final version of this article.

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