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Farmer's behavior in pesticide use: Insights study from smallholder and intensive agricultural farms in Bangladesh

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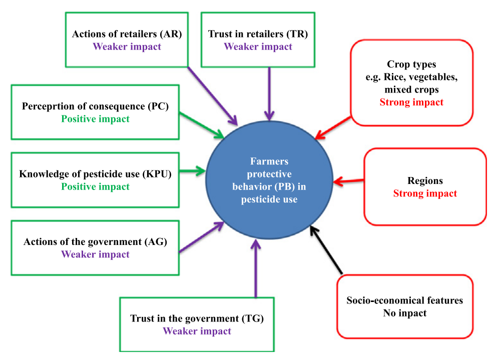
HIGHLIGHTS

- Pesticide use protective behavior (PB) largely influenced by crop grower and region.
- KPU and PC had strong positive effect on PBs.
- PBs negatively influenced by action of governments and trust of retailers.
- Gap exists between farmers, locations and action related authorities.
- To bridge the gap, policies need to address different stakeholders and locations.

GRAPHICAL ABSTRACT



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ABSTRACT

Since independence and over the years, pesticides have become a dominant feature of Bangladesh agriculture. To protect farmers' health, environment and to improve sustainability of chemical pest control quantitative understanding of farmers' behavior in pesticide use is critical. However, study on the levels of knowledge and awareness of farmers and the practices of pesticide use are often limited. We conducted a broad analysis on the effects of knowledge and awareness of farmers as well as the influence of the different associated stakeholders such as pesticide retailers and the government, on farmers' behavior in pesticide use from a detailed survey of 917 agricultural households in different regions of Bangladesh. Within eight protective behaviors (PBs) or PPEs were largely influenced by the crops growers and regions. Never discarding empty pesticide containers in the field, never applying pesticides more than prescribed by DAE or the instruction manual, selecting new types of pesticides recommended by DAE and purchasing low toxicity pesticides were the most adopted practices. Most farmers from the South-East region were adopting the PB of wearing mask, gloves and long sleeved clothes when spraying and farmers from South trusted the recommendations of pesticides by village leaders and neighbors. Majority of vegetables growers were well informed that pesticides were very harmful to the quality of agricultural products, the environment, and human health but not rice or mixed crops growers. Generally, PBs were positively affected by the perception of the consequences of farmers' behavior and knowledge of pesticide use but negatively

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influenced by action of governments and trust of retailers. It is important to recognize the differences that exist among different crops growers and locations. Attempt needs to bridge the gap among crop growers, locations and different stakeholder such as government agencies and retailers to develop policy.

1. Introduction

The global population is projected to be 9 billion by year 2050, and food availability and people's access to the food are matters that are increasingly important. Pesticides can help reduce the yield losses caused by the pests (e.g. insect pests, pathogens, weeds), and to feed the increasing world's population (Verger and Boobis, 2013). Agriculture is one of the most dangerous occupations although it is the second largest sector in the world as a source of work force. A large number of agricultural workers and farmers suffer from work accidents and diseases every year (ILO, 2010). Each and all individuals are faced with some types of pesticide exposure, but farmers and farming workers are particularly at high risk of pesticide exposure due to added risk of occupational exposure (Hashemi et al., 2012a).

Crop protection products particularly the use of pesticides against pests is one of several factors that are contributing to the huge growth in agricultural production. Pesticides are major inputs of the modern agricultural production, and due to their high capability and trustworthiness for crop protection against pests and warranty of high crop yields (Ahmed et al., 2011; Cooper and Dobson, 2007; Damalas, 2009; Fan et al., 2015). To protect human health against vector-borne diseases, for example, malaria, dengue, Zika fever, Chikungunya fever (Cuervo-Parra et al., 2016; WHO, 2009; Wilson and Tisdell, 2001), and to protect home sites, storages, lawns from weeds, pathogens and both insect and mammal pests pesticides are also used (Nayak et al., 2015; Sarwar, 2016; Spliid et al., 2004).

Pesticide use is viewed as an economic, labor-saving and efficient tool for pest management and for increasing crop production (Damalas and Eleftherohorinos, 2011). A number of researchers for example, Ahmed et al. (2002) and Travisi et al. (2006) indicated that despite positive effects of pesticides in agriculture and human well-being, their use also causes several risks to human health, non-target organisms and thus to the environment as a whole. Per year approximately five (5) billion kg of pesticides are applied in the world, which can have serious effects on non-target organisms, food chain and biodiversity, pretense high risks to human health and to the environment (Calliera et al., 2013; Miller, 2004; Verger and Boobis, 2013). Among the farmers and farm workers, approximately 43% of Zimbabwean, 25% of Mexican and 23% of Indian farmers and farm workers have been reported to suffer from work-related pesticide poisoning (FAO, 2014). As many as 25 million farmers and farm workers suffer from mild poisoning and three million farmers and farm workers suffer annually from serious pesticide poisoning, and resulting in approximately 180,000 fatalities among agricultural workers annually in rural areas of developing countries (Miller, 2004; Zhang et al., 2011), because of erroneous perceptions, lack of knowledge and education, regulation, unintentional application errors, for example, careless handling of pesticides, level of knowledge and education among farmers and farm workers (Damalas and Hashemi, 2010; Hashemi and Damalas, 2011; Hashemi et al., 2012b; Lekei et al., 2014; Khan et al., 2015).

Farmers in developing countries usually have too little knowledge on the proper handling of pesticides, and as a result, do not normally handle the products according to best agricultural practices (Houbraken et al., 2016; Ntow et al., 2006; Wumbei et al., 2019). Both acute and chronic health effects can occur due to exposure to pesticides. Researchers have shown the annual incidence rates of acute pesticide poisoning among agricultural workers to be as much as 18 per 100,000 full time workers and 7 per million among school-children (Thundiyil, 2008), and also chronic effect such as cancer in agricultural workers (Markel et al., 2015). While mixing, loading, or applying pesticides or through contact with treated crops during field re-entry, human and environmental exposure to pesticides can occur (Damalas and Eleftherohorinos, 2011; Remoundou et al., 2015).

Use of banned pesticides by authority or government (Van Hoi et al., 2009), overspray (Grovermann et al., 2013), lack of personal protection (Stadlinger et al., 2011), improper storage of pesticides and pesticide containers (Damalas et al., 2008; Ibitayo, 2006) and reuse of washed pesticide containers as containers for food and drinking water for example, approximately 35% and 77% of farmers in Nigeria and Ethiopia, respectively are most common unsafe or misuses phenomenon in developing countries (Karunamoorthi et al., 2012; Tijani, 2006). Different local (e.g. government authority) and international organizations (e.g. FAO, WHO) and other non-government organizations have taken initiatives to improve protective behaviors of farmers in pesticide use, including personal and environmental protection through education, legislation and community intervention. Those interventions are mostly focused on low- and middle-income countries e.g. Bangladesh, China, Indian and African countries although the results are often unsatisfactory (Dasgupta et al., 2005; Li et al., 2014; Stadlinger et al., 2013). The use of pesticides including personal and environmental protection is implemented by different national and international rules, regulations and directives e.g. FAO, WHO, EU directives through education, legislation and community intervention (Ahmed, 2008; Calliera et al., 2013; Calliera et al., 2016; Calliera and L'Astorina, 2018). Farmers' behavior in pesticide use can be influenced by a number of factors such as perceptions (Ahmed et al., 2011; Damalas and Hashemi, 2010; Hashemi and Damalas, 2011; Hashemi et al., 2012b; Mohanty et al., 2013; Khan et al., 2015), gender, age (Ahmed et al., 2011; Atreya, 2007; Damalas and Hashemi, 2010), level of knowledge and influences of pesticide retailers (Damalas et al., 2006a; Damalas et al., 2006b; Yang et al., 2014), and even crop growing cultural or planting differences (Van Hoi et al., 2009).

Bangladesh is one of the most densely populated, smallholder farms and intensive agricultural country, covers roughly 9.1 million hectares, which is 70% of the country's land area, to feed her more than 170 million inhabitants, of which more than 15 million are farming households, produced 38 million tons (MT) cereals, 0.4 MT pulses, 1.0 MT oilseed, 0.5 MT vegetables, 2.5 MT spices and condiments and GDP contribution from agriculture is 13.3% in 2018–2019 (BBS, 2020a). Approximately 87% of rural inhabitants' income derives from agricultural activities (BBS, 2016; WB, 2016a). In Bangladesh, increasing population, growing urbanization and infrastructure build-up for industrialization have put considerable pressure on arable land, which decreased from 0.11 ha/capita in 1980 to 0.05 ha/capita in 2014 while population reach more than double during the period (WB, 2016b). Moreover, 99% of farms are small-scale and fragmented, with an average land area of less than one hectare (BBS, 2016).

In Bangladesh, pesticide application has increased manifold from 758 metric tons in 1960 and 3028 metric tons in 1980 to over 19,000 metric tons in 2000. The amount of pesticide applied in fields across the country rose to 48,690 metric tons in 2008 (Islam et al., 2016; Miah et al., 2014). The use of toxic pesticides by Bangladeshi farmers increased by 328% during 1997–2008 posing a serious health hazards on human and environment due to long term residual effect (BRRI, 2012). This rapid increase in consumption of pesticide raises alarm about its potential impact on farmers' heath as well as on the environment particularly pesticide poisoning due to widespread use of banned pesticides in Bangladesh (IRIN, 2010). Inappropriate behavior of farmers towards pesticide use worsen the situation for example, more than 3.2 billion waste pesticide packages weighing 100,000 tons (with 2–5% of the total weight of residue pesticide) are randomly disposed annually in China (Jin et al., 2015) and over 47% of farmers overusing pesticides in Bangladesh (Dasgupta et al., 2005). Understanding farmers' behavior in pesticide use and the factors that affect such behavior is thus critical to the effective management, implementation, and dissemination of public policies. These issues, however, have rarely been studied particularly in intensive and smallholder farms like Bangladesh.

Agriculture is one of the human work activities connected with very high risk. Evidence across the world shows that there are multiple links between the practice and products of agriculture and environmental health risks (Sarkar et al., 2012). Studies on risk perception of agricultural workers are often connected with preventing any accident and occupational disease (Cecchini et al., 2018). Wide-spread use of pesticides and with the limited or poor literacy skills of farmers of Bangladesh, it is expected that occupational exposure to pesticides is likely to be high, cumulating the vulnerability to acute and chronic poisoning to human health and environment. This research study has focused on the farmers' knowledge level as well as attitudes towards and practices on safe pesticide use in a different locations or regions in Bangladesh. Also, the study has been inspired by a Chinese study (Fan et al., 2015) and we have followed that questionnaire with some modification. Our study aims (1) to determine and categorize the levels of knowledge, perceptions, and behavior associated with pesticide use in farmers of different types of crops, locations as well as the actions of pesticide retailers and the government, (2) to understand the driving key factors affecting farmers' behavior in pesticide use, and (3) to investigate and recommend options for building integrative links among authorities, pesticide retailers and farmers to improve safety in pesticide use in Bangladesh.

2. Materials and methods

2.1. Survey design and data collection

To understand the farmers' behavior on pesticide use, we interviewed 917 farmers in four geographic areas in Bangladesh. The four geographic areas were i. Southern covers Barisal and Jhalkathi administrative district (net cropped areas were 0.16 million hectares - Mha), ii. South-Western covers Satkira, Jhinaidah and Jashore (net cropped areas were 0.43 Mha), iii. Central-Northern (hereafter called as North) covers Sirajganj and Bogura (net cropped areas were 0.40 Mha), and iv. South-Eastern region covers greater Chattogram district, net cropped areas were 0.14 Mha (Fig. 1). The study areas represented the mix social and economic belt of the country (low and middle income households). However, most of the households depended on agriculture and rice was the main crop. There can also be found areas growing vegetables and mixed crops (e.g. Jashore and Bogura). Therefore, we selected the areas where rice was common; others were vegetables and mixed crops growers. A major source of representative local level social and economic data for those areas (e.g. district) is the National Population and Housing Census (PHC) in 2011 (BBS, 2020b).

The data were collected by interviewing households using a pre-structured questionnaire. Face-to-face interviews (literacy rate only about 44.7% in 2011; BBS, 2015) using these structured questionnaires were conducted by trained agricultural field assistants recruited in “partnership enhancement and engaged in research (PEER) Project” supported by USAID. The recruited field assistants were trained by a research team in Bangladesh Rice Research Institute (BRRI) before conducting field study. The interviewers were supervised by the research team and lead author also participated to take interview. The questionnaires were developed by the research team and also piloted before being used in the field. The households were selected randomly from the villages of different upazillas and districts within four geographic areas (Fig. 1) with the consultations of Department of Agricultural Extension (DAE), Bangladesh. The personnel such as Sub-

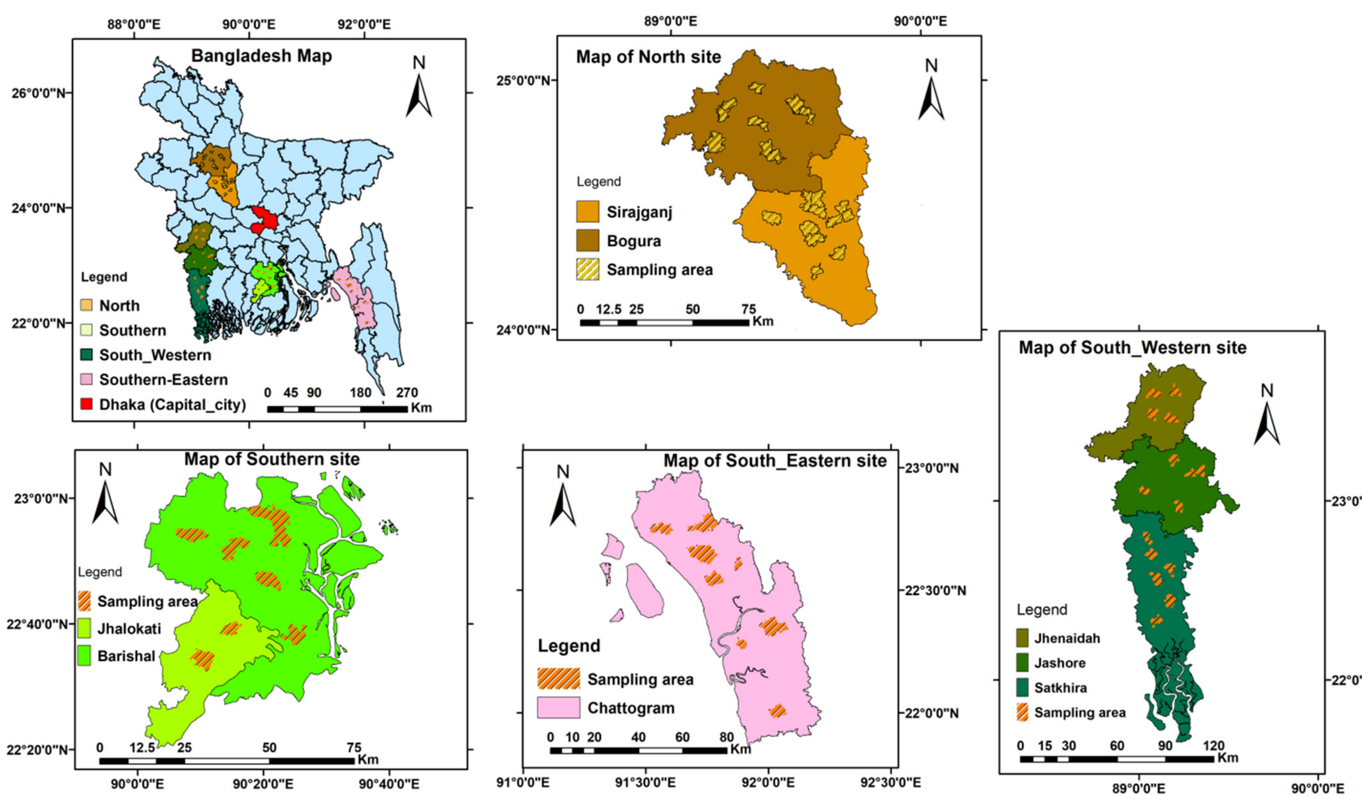

Fig. 1. Map of Bangladesh showing the different surveyed regions.

Assistant Agricultural Extension Officer (SAAO) of DAE usually work at the village level and give the advice in all kinds of agricultural aspects. There are rare records to get formal farmer's registers in Bangladesh. So, we selected the farmers in consultations of SAAO. The questionnaire was prepared based on 43 individual questions with some basic information e.g. age, gender, household size, number of household members, household income and education as well as behaviors related questions. To validate the suitability of the prepared questionnaire, firstly a pre-survey of 32 households were conducted to get the appropriate answers of all the questions mentioned in the questionnaire. After this pre-survey, we modified the questionnaire slightly and fixed the questionnaire with 43 questions with key information on the knowledge, attitudes, perceptions and behavior of local farmers regarding pesticide use (Appendix A). Then we interviewed 917 households randomly from four geographic regions (described above). One family member from each household who used pesticide was interviewed. Questions were asked serially from first to last and provided enough time to think the question and gave appropriate answer. Since most of the respondents were illiterate/primary educated, we sometimes had to explain the questions to obtain correct answer. The respondents were entirely volunteers and had freedom to refuse to give us information in time of explanation. However, nobody denied giving interview. Each respondent got a USD 0.75 gift (soap) as incentive for their time investment. The gift was given after interviewing the respondents. This type of gift makes refreshment of interviewed respondents. Since it was given after interviewing it did not influence the answers of the respondents. This incentive had an especial motive to wash their hand using the received soap after spraying pesticides in the crop fields. The interview was conducted from January 2018 to May 2018 covering rice, vegetable and other mixed crops growing periods in Bangladesh.

We did not get any refusals or any incomplete questionnaires. Of the 917 households with fully completed questionnaires, 490 households cultivated rice, 252 cultivated vegetables, and the remainder (N = 175) cultivated a mixture of rice, vegetables and fruits. We asked for the characteristics of each respondent who handled pesticides (age, gender, educational level, household income, arable land and net family size) and included 30 questions on their knowledge of pesticide applications (KPU; seven questions; Table 2), perceptions of the consequences of their behavior (PC; four questions; Table 3), selecting, storing, and applying pesticides (PBs; eight questions; Table 4), awareness of the actions of pesticide retailers (action of retailers-AR, three questions; trust in pesticide retailers-TR, two questions; Table 5) and awareness of the action of the government (actions of the government-AG, three questions; trust in the government-TG, three questions; Table 6). We considered a five-point Likert scale from 1 = very unlikely to 5 = very likely, to quantify the answers in the questionnaire. Occasionally this coding was considered to reflect outcomes on an interval scale, making possible comparisons of averages and covariance measures.

2.2. Data analysis

The data from the 917 fully completed questionnaires were coded and analyzed using SPSS 26.0 (SPSS, 2019) and R 'lavaan' package (Rosseel, 2012). Descriptive measures of socio-economic characteristics of the subpopulations are given in Table 1. Differences between crop types and regions were tested with χ^2- homogeneity test on interval categorized socio-economic variables. We assessed the internal consistency of question items in the questionnaire using Cronbach's α test. Although in some cases Cronbach's α-values were low, most of the cases had Cronbach's α-values fairly high (Tables 2–6). An α-value greater than 0.7 indicates good internal consistency (Chung et al., 1998). We compared the characteristics, knowledge, perceptions and practices of pesticide use of the respondents along with their awareness of pesticide retailers and the government involvement among the different groups of farmers (i.e. rice, vegetable, and mixed-crop groups) and the four different regions.

We calculated the means and standard deviations of the responses obtained in each group (crop types and regions) for each question based on the five-points Likert scale and reported those values in Tables 2–6. The distributions of answers in the different groups were shown in Figs. B1–B30 in Appendix B as well as indicated by different letters in Tables 2–6.

We also used a general linear model (GLM) to estimate the influences on protective behaviors (PBs; calculated as the average Likert values over the eight questions) from several explanatory category-variables e.g. age, family size, farm size, income group, crop types and regions as well as covariates such as KPU, AR, TR, AG, TG, PC; each calculated as the average of the Likert values over the questions in each factor. The beta values (β) from this regression model were reported in Tables 7 and 8 for different groups.

We also built a structural equation model using R 'lavaan' package to depict the general relationships among the characteristics, level of knowledge, and perceptions of farmers about pesticide use and their awareness of pesticide retailers and the government involvement. The resulting models from this analysis are depicted in Figs. 4 and 5 showing the influences from factors KPUf, ARf, TRf, AGf, TGf and PCf on the factor

Table 1
Descriptive statistics among different crop growers and regions.

Questionnaire item		Crop types			Regions			
		Rice	Vegetables	Mixed crops	South-West	South-East	North	South
Age (years)	Mean	47.6	45.6	48.1	46.3	46.9	47.4	49.2
	SD	12.5	13.1	13.2	12.9	12.5	12.5	14.2
	N	490	249	174	431	158	155	169
	Distribution	a	a	a	B	C	C	A
Family size (No.)	Mean	5.0	4.7	5.1	4.8	5.7	4.0	5.3
	SD	1.8	1.6	2.0	1.7	2.1	1.2	1.6
	N	490	249	174	431	158	155	169
	Distribution	a	a	a	B	A	C	A
Farm Size ('Bigha'/household)	Mean	4.4	3.7	5.2	3.7	5.7	5.4	4.0
	SD	3.7	5.0	5.8	4.2	6.7	4.2	2.3
	N	490	249	174	431	158	155	169
	Distribution	a	b	c	A	B	B	C
Income (Taka/day)	Mean	438.6	462.2	506.6	404.0	654.4	425.8	441.7
	SD	154.5	159.2	221.5	137.6	189.7	135.6	130.4
	N	490	249	174	431	158	155	169
	Distribution	b	c	a	B	A	C	C

Different letters within a row indicate statistically significant differences in distribution of categorized variables at $p < 0.05$ at crop types (small letter) and regions (capital letter) respectively.
1 ha =4 'Bigha's'.

Table 2
Knowledge of pesticide use (KPU) among groups of farmers and regions.

Questionnaire item		Crop types			Regions			
		Rice	Vegetables	Mixed crops	South-West	South-East	North	South
Know about pesticide toxicity	Mean	3.11	3.07	3.19	2.67	4.39	3.17	2.98
	SD	1.39	1.74	1.44	1.44	1.10	0.95	1.72
	Distribution	a	b	c	A	B	C	D
Read and understand instruction manual and pesticide labels	Mean	2.93	2.99	3.02	2.81	3.87	2.79	2.65
	SD	1.76	1.84	1.72	1.86	1.38	1.59	1.77
	Distribution	a	b	b	A	B	A	A
Know why some pesticides are currently banned for use	Mean	4.24	4.55	4.23	4.41	4.85	3.59	4.27
	SD	1.13	1.13	1.18	1.19	0.60	1.10	1.15
	Distribution	a	b	c	C	B	A	B
Pesticides are very harmful to agricultural products	Mean	3.06	3.30	3.14	2.90	4.53	2.72	3.28
	SD	1.22	1.51	1.27	1.23	0.83	0.89	1.31
	Distribution	a	b	c	A	B	A	C
Pesticides are associated with current human illnesses	Mean	3.14	3.46	3.39	2.90	4.57	2.92	3.32
	SD	1.22	1.36	1.27	1.23	0.85	0.84	1.28
	Distribution	a	b	c	A	B	C	D
The environment is highly affected by pesticide use	Mean	3.51	3.52	3.54	3.08	4.63	3.60	3.51
	SD	1.26	1.50	1.31	1.40	0.82	0.88	1.32
	Distribution	a	b	c	A	B	C	D
Know pesticide effects on the body	Mean	3.52	3.56	3.43	3.28	4.61	2.37	4.10
	SD	1.39	1.42	1.36	1.38	0.85	0.92	1.20
	Distribution	ns	ns	ns	A	B	C	D
N		487	252	173	430	159	155	169
Cronbach's α		0.824	0.871	0.854	0.830	0.839	0.361	0.832

Notes: Mean values of scores in the table using a scale from1 to 5: 1 = very unlikely; 2 = somewhat unlikely; 3 = unsure; 4 = somewhat likely; 5 = very likely. Different letters within a row indicate statistically significant differences in distribution at $p < 0.05$ at crop types (small letter) and regions (capital letter) respectively.

PBf. Here we assumed that all the factors were uncorrelated and 'f' stands for the factor scores obtained from the structural equation models with independent factors. The factors obtained in this way thus differ to some extent from those obtained from the averages of the question responses in each factor, which is also reflected in the varying magnitude of the factor loadings to the corresponding questions in Figs. 4 and 5.

Initially, we studied the pattern of responses on research questions for the whole group of farmers. In order to understand the underlying factors determining the response pattern on the 30 questions from each of the farmers, we used a two-factor principal component analysis on the 30 × 30 dimensional covariance matrix constructed from the indices obtained from transforming the five-step ordinal Likert scale into integer values 1 to 5. The covariance matrix, calculated on the basis of the 917 responses on the 30 questions, reflects to some extent the simultaneous response pattern between questions for individual farmers.

The resulting factor scores for the individual farmers are depicted in Fig. 6 and Fig. 7 classified into either farmers from the particular region (Fig. 6) or the crops types that the farmers mainly cultivated (Fig. 7).

3. Results

3.1. Respondents' characteristics

Among the 917 farmers, 914 were male farmers; only three were female farmers - one from each region except North. In Bangladesh, farming and farm holding is generally maintained by male, however in some areas there are also female maintained farms particularly in tribal areas. The present study did not consider those tribal areas. The selected geographical areas were chosen on the basis of crops grown not on gender basis. Therefore, the sample of farmers was dominated by males, and gender was not considered as an influential variable. Among the

Table 3
Perceptions of the consequences (PC) of pesticide use among groups of farmers and regions.

Questionnaire item		Crop types			Regions			
		Rice	Vegetables	Mixed crops	South-West	South-East	North	South
It will be very detrimental to my health if I do not protect myself when spraying pesticides	Mean	2.68	3.30	2.87	2.88	3.53	2.42	2.72
	SD	1.26	1.30	1.31	1.34	1.21	0.86	141
	Distribution	a	b	c	A	B	C	D
The current environment will improve if I spray less pesticide	Mean	3.94	4.13	3.86	3.99	4.74	3.26	3.86
	SD	1.14	1.03	1.16	1.11	0.70	1.08	1.05
	Distribution	ns	ns	ns	A	B	C	A
Spraying less pesticide will reduce my income from production	Mean	3.80	4.26	3.70	3.84	4.81	3.19	3.87
	SD	1.16	1.11	1.24	1.20	0.60	1.14	1.05
	Distribution	a	b	c	A	B	C	A
Spraying more pesticides will not lower product price	Mean	3.12	3.18	3.08	2.48	4.87	2.42	3.78
	SD	1.37	1.84	1.52	1.49	0.51	0.97	1.11
	Distribution	a	b	c	A	B	C	D
N		486	252	173	429	159	155	169
Cronbach's α		0.617	0.601	0.776	0.508	0.652	0.291	0.712

Notes: Mean values of scores in the table using a scale from1 to 5: 1 = very unlikely; 2 = somewhat unlikely; 3 = unsure; 4 = somewhat likely; 5 = very likely. Different letters within a row indicate statistically significant differences in distribution at $p < 0.05$ at crop types (small letter) and regions (capital letter) respectively.

Table 4
Protective behavior (PB) in pesticide use among groups of farmers and regions.

Questionnaire item		Crop types			Regions			
		Rice	Vegetables	Mixed crops	South-West	South-East	North	South
Wearing masks, gloves, and long-sleeved clothes when spraying pesticides	Mean	2.57	3.45	2.72	2.58	4.09	2.40	2.73
	SD	1.23	1.26	1.32	1.28	0.93	0.79	1.39
	Distribution	a	b	c	A	B	C	D
Changing clothes or showering immediately after spraying pesticides	Mean	1.28	1.29	1.28	1.14	1.46	1.36	1.39
	SD	0.67	0.81	0.71	0.55	0.88	0.71	0.86
	Distribution	ns	ns	ns	A	B	B	B
Carefully storing pesticides in a safe place after purchase	Mean	1.46	1.26	1.33	1.30	1.13	1.73	1.48
	SD	0.86	0.88	0.77	0.85	0.62	0.84	0.96
	Distribution	a	b	c	A	B	B	B
Never discarding the empty pesticide containers in the field after use	Mean	3.69	3.27	3.58	3.61	4.12	2.99	3.38
	SD	1.59	1.85	1.67	1.77	1.42	1.39	1.78
	Distribution	a	b	c	A	B	C	A
Never applying pesticides more than prescribed by Department of Agricultural Extension (DAE) or the instruction manual	Mean	4.09	4.60	4.05	4.66	4.54	3.64	3.34
	SD	1.16	1.00	1.29	0.95	1.08	0.99	1.19
	Distribution	a	b	c	A	A	B	B
Selecting new types of pesticides recommended by DAE	Mean	4.12	4.61	4.06	4.62	4.57	3.66	3.54
	SD	1.15	0.95	1.27	0.98	1.02	1.02	1.20
	Distribution	a	b	c	A	A	B	B
Low toxicity is the main reason for selecting and purchasing pesticides	Mean	4.51	4.55	4.31	4.67	4.60	3.96	4.47
	SD	0.95	1.03	1.23	0.88	1.03	1.21	1.07
	Distribution	a	b	c	A	A	B	A
Reading the instructions on the pesticide carefully before spraying	Mean	2.92	3.00	2.97	3.10	3.55	2.12	2.70
	SD	1.72	1.87	1.77	1.86	1.64	1.29	1.76
	Distribution	a	b	c	A	B	C	A
N		485	252	173	430	159	154	168
Cronbach's α		0.621	0.563	0.724	0.507	0.699	0.430	0.734

Notes: Mean values of scores in the table using a scale from1 to 5: 1 = very unlikely; 2 = somewhat unlikely; 3 = unsure; 4 = somewhat likely; 5 = very likely. Different letters within a row indicate statistically significant differences in distribution at $p < 0.05$ at crop types (small letter) and regions (capital letter) respectively.

responding farmers more than 73% were aged between 30 and 60 years. A small fraction, 15% of farmers were at aged over 60 years.

About 40% of the households were three (3) to four (4) members and almost the same percentages of households consisted of five (5) to six (6) members. The majority of the rest were larger households with more than six (6) members and a very small fraction, 5% were only two (2) members in a family.

Among the responding farmers, about 54% (500) mentioned their education level. Among those about 28% were illiterate, 49% had primary education (≤5 years education) and 23% had secondary and up to university education. However, it is very common to find illiterate farmers in Bangladesh. So the present scenario is little bit misleading the distribution of educational level among the responding farmers.

Table 5
Awareness of the actions of pesticide retailers among groups of farmers and regions.

Questionnaire item		Crop types			Regions			
		Rice	Vegetables	Mixed crops	South-West	South-East	North	South
Actions of retailers (AR)								
Retailers tend to recommend new types of pesticides when selecting pesticides	Mean	2.26	2.63	2.46	2.56	2.15	2.18	2.43
	SD	0.91	1.11	1.00	1.00	1.00	0.78	1.08
	Distribution	a	b	c	A	B	B	B
Retailers give guidelines on pesticide use after sales	Mean	2.56	2.79	2.60	2.66	2.54	2.63	2.63
	SD	1.21	1.29	1.28	1.16	1.28	1.32	1.37
	Distribution	ns	ns	ns	A	A	B	A
Retailers suggest ways to protect farmers when using the pesticides	Mean	3.03	3.33	2.95	2.95	2.81	4.10	2.81
	SD	1.45	1.53	1.49	1.43	1.53	1.07	1.54
	Distribution	ns	ns	ns	A	A	B	A
N		486	252	173	430	158	155	169
Cronbach's α		0.428	0.392	0.475	0.536	0.316	0.082	0.572
Trust in retailers (TR)								
Believing the suggestions of retailers when they recommend pesticides	Mean	2.60	2.99	2.47	2.25	3.53	2.95	2.73
	SD	1.39	1.46	1.37	1.39	1.68	0.86	1.22
	Distribution	b	a	c	A	B	C	D
Believing the instructions of retailers on pesticide use and how to protect farmers	Mean	3.40	3.70	3.43	3.71	3.67	2.86	3.32
	SD	1.34	1.71	1.42	1.55	1.68	0.89	1.30
	Distribution	b	a	c	A	B	C	D
N		486	252	173	430	159	155	168
Cronbach's α		0.451	0.152	0.418	0.244	0.471	0.248	0.021

Notes: Mean values of scores in the table using a scale from1 to 5: 1 = very unlikely; 2 = somewhat unlikely; 3 = unsure; 4 = somewhat likely; 5 = very likely. Different letters within a row indicate statistically significant differences in distribution at $p < 0.05$ at crop types (small letter) and regions (capital letter) respectively.

Table 6
Awareness of the actions of the government among groups of farmers and regions.

Questionnaire item		Crop types			Regions			
		Rice	Vegetables	Mixed crops	South-West	South-East	North	South
Actions of the government (AG)								
Technical staff of local government provides suggestions for selecting and using pesticides	Mean	2.96	2.75	3.07	2.37	4.04	2.99	3.25
	SD	1.39	1.47	1.35	1.29	1.34	1.38	1.07
	Distribution	b	c	a	A	B	C	D
The local government tells us that pesticides are harmful to the environment through e.g. TV, newspapers, radios	Mean	2.59	2.72	2.58	2.02	4.03	2.15	3.25
	SD	1.26	1.45	1.26	0.92	1.34	1.03	1.07
	Distribution	b	a	b	A	B	C	D
Community leaders often recommend new kinds of pesticides	Mean	3.46	3.98	3.54	3.83	2.30	3.06	4.85
	SD	1.40	1.52	1.42	1.30	1.51	1.10	0.61
	Distribution	c	a	b	A	B	C	D
N		487	252	173	430	159	155	169
Cronbach's α		0.530	0.220	0.153	0.381	0.546	0.449	0.663
Trust in the government (TG)								
Believing the suggestions of technical staff for selecting and using pesticides	Mean	2.33	3.63	2.50	2.52	3.60	1.51	3.57
	SD	1.46	1.44	1.54	1.54	1.71	0.72	1.15
	Distribution	c	a	b	A	B	C	D
The governmental information that a pesticide is harmful to the environment is true and not an overstatement	Mean	2.67	3.54	2.77	2.81	3.66	1.75	3.70
	SD	1.36	1.27	1.32	1.23	1.70	0.67	0.99
	Distribution	c	a	b	A	B	C	D
The recommendations of pesticides by village leaders and neighbors can be trusted	Mean	2.91	2.96	2.83	2.46	1.99	3.20	4.59
	SD	1.57	1.38	1.45	1.35	1.40	0.90	0.85
	Distribution	a	a	b	A	B	C	D
N		474	252	173	430	146	155	169
Cronbach's α		0.766	0.509	0.606	0.788	0.585	0.292	0.570

Notes: Mean values of scores in the table using a scale from1 to 5: 1 = very unlikely; 2 = somewhat unlikely; 3 = unsure; 4 = somewhat likely; 5 = very likely. Different letters within a row indicate statistically significant differences in distribution at $p < 0.05$ at crop types (small letter) and regions (capital letter) respectively.

About 29% of the responding farmers had very small farm land with the size less than 2 'Bigha' (4 Bighas = 1 ha), 36% farmers had more than 2 and up to 4 'Bigha' and 28% had more than 4 and up to 8 'Bigha' and only 7% had more than 8 'Bigha' land.

Approximately 5% farmers had income less than Taka 250/= per day, about 49% had daily income Taka 250 to 400 per day, about 43% had daily income more than Taka 400 to 800 and only 3% had daily income more than Taka 800 (1 US$ = Taka 80).

Among the responding farmers, about 47% were from South-West region while the remaining farmers were almost equally spread over the three other regions (North - 17%, South - 19% and South-East- 17%).

About 53% responding farmers rice, 28% farmers grew vegetables, 19% farmers grew mixed crop. There was only one fruits grower, which however was excluded from further analysis.

Descriptive measures of respondents' characteristics such as age, family size, farm size and daily income distribution were shown in Table 1, also indicating differences in distribution for different crops growers and regions. Although statistically significant differences can be seen in many of the characteristics between the crop type growers' subpopulations or the location wise defined populations of growers, the differences are not always very extreme/large. In some cases however, e.g. the income distribution in South-East was much wider in range (variation) as well as generally higher income than in other regions.

3.2. Association among the respondents' characteristics

Among the respondents' characteristics, we found notable association between for example, regions and income, regions and crop grown, farm size and regions.

In general, it seems not to be indication of differences in income between different age groups. Not surprisingly there was a significant difference in the family size distribution between the young aged group and the family size distribution in older aged groups.

Number of family members and their income had a significant relationship i.e. those who had no children or family member had less income as compared to those groups who had more than two family members and up to more than six family members. In contrast with family member and age groups, there seems to be no significant relationship between farm size distribution and age groups.

Farm size and income had a significant relation i.e. increasing the farm size increased the income. Farm size and number of family member had a significant relation i.e. increasing the family members related to their farm size, larger farm size holder farmers had higher number of family members than that of the small farm holders. However, conditioning on income groups gave independence between farm size and number of family members (family size groups), which indicated both farm size and family size groups were dependent on income groups.

Smaller farm holders were more prevail in South-West region compared to other regions. The highest percentage of larger farm size was found in the Northern region. Number of family members were also significantly varied with regions i.e. South-East, South and South-West regions farm holders had more number of members or children or extended family members than the Northern region. Significantly more number of aged farmers were involved in agriculture in Southern region compared to other regions.

South-East region farm holders had significantly higher income than the South, South-West and Northern regions. As seen (Fig. 2) the low income group (≤Taka 250/day) was completely missing in the South-East regions (location). For the other three regions relative prevalence of all four income groups was almost same. However, in the North region, the highest income group (> Taka 800/day) was absent.

Significantly more numbers of illiterate farmers were involved in agriculture in South-East, South and Northern regions compared to the South-West region. Most of the farmers in all regions involved in agriculture had at most primary level education (Fig. 3). This conclusion is based on five hundred (500) respondents from all four regions obtained in a post-survey after the completion of the actual survey. Since this information about education level is only available for 54% of the total respondents (917), we have excluded the education level as an explanatory factor from the further analysis. We excluded education level from the model since (i) a major part of farmers are illiterate

Table 7
Coefficients between farmers' protective behavior (PB) in pesticide use and 10 factors among the different groups of farmers.

Factor	Aggregate	Aggregate (considering crop type and regions as factors)
Age group (age)	NS	NS
≥ 18 to ≤ 30	−1.852 (107)	−0.079 (107)
>30 to ≤ 45	−0.393 (335)	−0.045 (334)
>45 to ≤60	0.023(335)	−0.011 (335)
>60	0[a] (133)	0[a] (133)
Family size group (members)	NS	NS
≤2	0.148 (47)	0.066 (47)
>2 to ≤4	0.302 (372)	−0.004 (372)
>4 to ≤6	0.382 (348)	0.055 (348)
>6	0[a] (143)	0[a] (142)
Farm size ('Bigha'/household)	NS	NS
≤2	−0.617 (265)	0.010 (265)
>2 to ≤4	−2.615 (332)	−0.048 (332)
>4 to ≤8	−0.018 (252)	−0.030 (252)
>8	0[a] (61)	0[a] (60)
Income group (Taka/day)	NS	NS
≤250	2.631 (41)	0.218 (41)
>250 to ≤400	2.925 (452)	0.230 (452)
>400 to ≤800	1.113 (394)	0.164 (394)
>800	0[a] (23)	0[a] (22)
Crop types		**
Rice		0.080 (487)
Vegetables		−0.061 (249)
Mixed crops		0[a] (173)
Regions		***
North		0.015 (155)
South		−0.230 (169)
South-West		0.387 (427)
South-East		0[a] (158)
KPU	0.234***	0.264***
AR	−0.042	−0.040*
TR	0.088***	0.061**
AG	0.020	0.086***
TG	−0.072***	−0.011
PC	0.247***	0.239***

NS means non-significant differences; 1 ha =4 'Bigha's'.
[a] The last category parameter is set to zero and the other categories parameter express the difference to the last category. KPU, knowledge of pesticide use; AR, actions of retailers; TR, trust in retailers; AG, actions of the government; TG, trust in the government; PC, perceptions of the consequences of the behavior.
* Significant at $p < 0.05$.
** Significant at $p < 0.01$.
*** Significant at $p < 0.001$.

(more than 55%) and this is not reflected in our subsample, and (ii) when considering the subsample for which education level were obtained (500) of the 917, no significant influence was obtained in the regression model.

Smaller farm size holders were relatively more educated than the larger farm holders. There were some indications that the higher income groups had relatively lower education. Basic education e.g. primary level seems to give higher income compared to uneducated farmers. However, this tendency was not obvious for even higher education e.g. secondary and above level.

Level of education and different crop growing pattern had significant relationship. Farmers with education at least secondary education level had grown vegetables and mixed crops more than compared to farmers with no education or primary education. Farmers with up to primary education mostly grew rice. Distribution of crops grown seems to be independent of age group/the same regardless of age. Dominancy of rice growing was increasing with the increase of farm size. Small farm size holders mainly produced either rice or vegetables. Farmers in North and South regions mostly grew rice. In South-East and South-West regions farmers were either rice or vegetables grower with almost equal proportion.

Almost all farmers within the sample regions used pesticides (particularly insecticides), except four (4) crops growers and those four growers belonged to the South-West region. Three were growing rice and one grew mixed crops.

3.3. Knowledge, perceptions, and behavior of farmers

Among the vegetables growers, a majority were well informed that pesticides were very harmful to the quality of agricultural products, the environment, and human illness. However, among the rice growers, and mixed crops growers, this tendency was not that clear for harmfulness to the quality of agricultural products and to human health as well, although they were well informed that pesticides were very harmful to the environment. Actually, the differences among the farmers groups of different crop growers could often be seen rather clearly in the answering distribution patterns among the crops growers (Table 2 and Figs. B4–B6 in Appendix B).

Among the respondents from the North region, the majority was not well informed that pesticides were very harmful to the quality of agricultural products, and human illness. However, they were well informed that pesticides were very harmful to the environment. In the South region, on the contrary, the majority were well informed that pesticides were very harmful to the quality of agricultural products, the environment, and human illness. Similarly, in the South-East region, the majority were well informed that pesticides were very harmful to the quality of agricultural products, the environment, and human illness. In the South-West, on the other hand, the distribution of information ranges from uninformed to well informed in an equal numbers regarding all three questions (Table 2 and Figs. B4–B6 in Appendix B).

Among the vegetables growers, almost equal numbers of respondents were well informed as those not informed about pesticide toxicity; they were however well informed that how pesticides affect the body. For rice growers and mixed crops growers, the knowledge of pesticides toxicity was uniformly distributed among their response alternatives. For that how pesticides affect the body, the majority of rice growers and mixed crops growers were well informed (Table 2 and Figs. B1 & B7 in Appendix B).

In the South region, equal numbers of respondents were well informed as those not informed about pesticide toxicity. In the South-East region, a majority of respondents were well informed.

In the South-West and the North regions, the respondents' opinions were more uniformly distributed among the alternatives (Table 2 and Fig. B1 in Appendix B). For the South and the South-East regions, majority were well informed that pesticides affect the body. On the contrary, in the North region, the majority were not well informed. In the South-West region, the conclusion was not clear (Table 2 and Fig. B7 in Appendix B).

Among the all types of crops growers, almost equal numbers of respondents were reading the pesticide manual as those not reading the manual. Similar tendencies were also found for the North, South, and South-West regions. In the South-East region, however, the majority was reading the pesticide manual (Table 2 and Fig. B2 in Appendix B).

Among all crops growers and respondents from all regions, a majority were well informed why pesticides are currently banned (Table 2 and Fig. B3 in Appendix B).

The rice growers and the respondents from North and South regions did not believe that 'pesticides are detrimental to their own health' compared to other crops growers and regions which were more uniformly distributed among the alternatives (Table 3 and Fig. B8 in Appendix B). Different crops growers and the respondents from all regions had a clear idea of that spraying less pesticide would reduce their yields and incomes but also improve the current environment, especially the vegetable farmers among the crops growers and the respondents from the South-East region (Table 3 and Figs. B9 & B10 in Appendix B).

Among the different crops growers, vegetables farmers had either a clear idea that spraying more pesticides will not lower the product price

Table 8
Coefficients between farmers' protective behavior (PB) in pesticide use and 10 factors among the different groups of farmers.

Factor	Crops			Regions			
	Rice	Vegetables	Mixed	South-West	South-East	North	South
Age group	NS	NS	NS	NS	NS	NS	*
≥18 to ≤ 30	0.316(52)	0.284(37)	−2.385(18)	0.459(61)	1.371(14)	0.170(12)	−0.996(20)
>30 to ≤ 45	−0.730(179)	−1.719(90)	−0.880(65)	−1.313(150)	0.366(63)	0.090(67)	0.450(55)
>45 to ≤60	−0.348(182)	−0.384(96)	−1.014(57)	−0.553(163)	0.332(59)	0.495(58)	0.013(55)
>60	0[a] (74)	0[a] (26)	0[a] (33)	0[a] (54)	0[a] (22)	0[a] (18)	0[a] (39)
Family size group	NS	NS	NS	NS	NS	NS	NS
≤2	−0.145(28)	0.437(15)	0.435(4)	−0.564(23)	0.075(4)	−0.436(16)	0.923(4)
>2 to ≤4	0.493(190)	2.429(108)	−1.254(74)	−0.281(190)	0.305(39)	0.026(90)	0.250(53)
>4 to ≤6	1.164(186)	0.731(100)	−0.744(62)	−0.572(149)	0.071(75)	−0.231(46)	0.519(78)
> 6	0[a] (83)	0[a] (26)	0[a] (33)	0[a] (66)	0[a] (40)	0[a] (3)	0[a] (34)
Farm size ('Bigha'/household)	NS	NS	NS	NS	NS	NS	NS
≤2	1.090(127)	−2.296(114)	−1.042(24)	−0.395(164)	0.546(36)	0.070(21)	−0.660(44)
>2 to ≤4	−1.277(178)	−0.342(79)	−2.179(75)	0.827(158)	−0.014(53)	0.578(56)	−1.814(65)
>4 to ≤8	0.468(148)	−0.553(44)	−1.628(60)	−1.259(88)	−0.065(53)	0.007(59)	−0.464(52)
>8	0[a] (34)	0[a] (12)	0[a] (14)	0[a] (18)	0[a] (16)	0[a] (19)	0[a] (8)
Income group (Taka/day)	NS	NS	NS	*	NS	NS	NS
≤250	−0.495(28)	0.350(8)	1.205(5)	3.290(30)	–	−1.783(7)	1.755(4)
>250 to ≤400	−1.790 (256)	−0.866 (114)	4.125 (82)	1.708 (259)	0.007(4)	−0.509(88)	−0.079(101)
>400 to ≤800	−0.771(197)	0.846(123)	−0.147(74)	0.083(134)	0.043(139)	0[a] (60)	0.414(61)
>800	0[a] (6)	0[a] (4)	0[a] (12)	0[a] (5)	0[a] (15)	–	0[a] (3)
KPU	0.246***	0.232***	0.221***	0.268***	0.370***	0.200	0.236***
AR	−0.010	−0.047	−0.164**	−0.041	−0.015	−0.111	0.118
TR	0.086*	0.045	0.076	0.083**	0.014	0.056	−0.015
AG	0.025	0.016	0.148*	−0.025	0.018	0.084	0.369***
TG	−0.131***	0.081	−0.140*	−0.060*	0.052	0.007	−0.056
PC	0.181***	0.177***	0.401***	0.166***	0.483***	0.316***	0.346***

NS Means non-significant difference; 1 ha =4 'Bigha's'.
[a] The last category parameter is set to zero and the other categories parameter express the difference to the last category. KPU, knowledge of pesticide use; AR, actions of retailers; TR, trust in retailers; AG, actions of the government; TG, trust in the government; PC, perceptions of the consequences of the behavior.
* Significant at $p < 0.05$.
** Significant at $p < 0.01$.
*** Significant at $p < 0.001$.

or showed a clear opposite opinion. Among rice and mixed crops growers, the opinions were more ambiguous. The respondents from North region mostly believed that it is unlikely that spraying more pesticides will not lower the product price but the opinion of the respondents from South-East region was quite opposite. However, the opinions of the respondents from other two regions were ambivalent (Table 3 and Fig. B11 in Appendix B).

Different crops growers and the respondents from all regions reported eight protective behaviors (PBs) in using pesticides (Figs. B12–B19 in Appendix B), but only four PBs (Figs. B15–B18 in Appendix

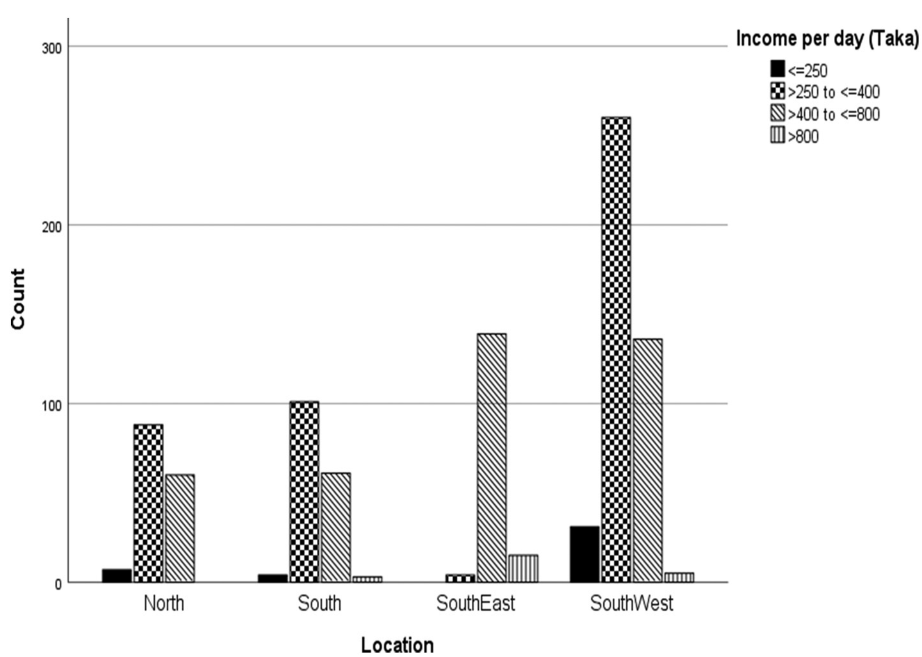

Fig. 2. Income distribution of farmers in different regions of Bangladesh.

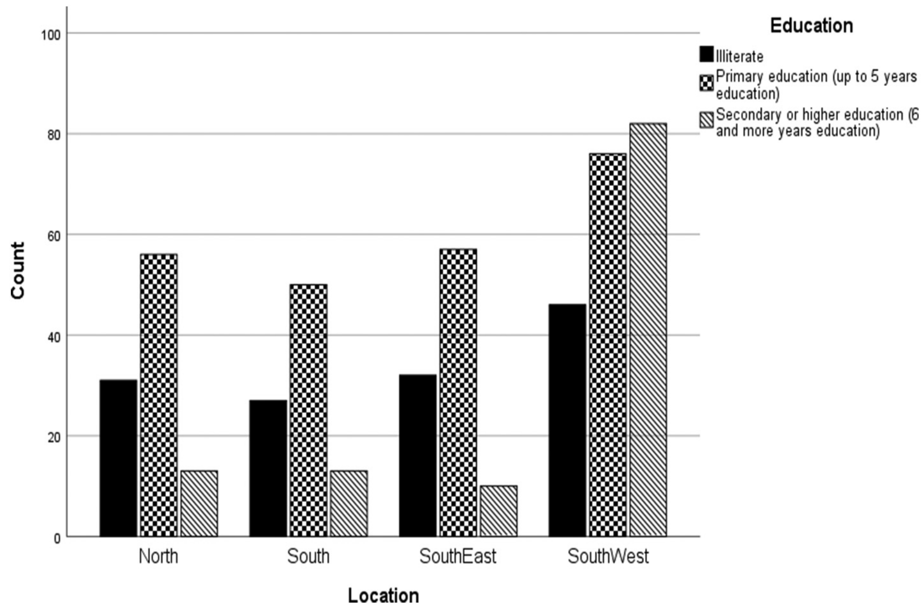

Fig. 3. Education level of farmers in different regions of Bangladesh.

B) were adopted by the majority of the respondents (Table 4). However, the opinions from the North region were more or less ambivalent.

Carefully and safely storing pesticides and changing clothes or showering after spraying were the least frequently practiced PB, on the other hand, never discarding empty pesticide containers in the field, never applying pesticides more than prescribed by Department of Agricultural Extension (DAE) or the instruction manual, selecting new types of pesticides recommended by DAE and purchasing low toxicity pesticides were the most adopted practices (Table 4). Notably, a large extent of the respondents from the South-East region were adopting the PB of wearing mask, gloves and long sleeved clothes when spraying (Fig. B12 in Appendix B).

3.4. Awareness of retailer

The respondents received little information from pesticide retailers about the selection of pesticides, guidelines on pesticides use, ways to protect farmers when using pesticides (Table 5 and Figs. B20–B22 in Appendix B).

The rice growers did not believe (trust) the suggestion of retailers regarding recommendation of pesticides but they believed retailers instruction on pesticide use and how to protect farmers. For the other crops growers the opinions were not that clear (Table 5 and Figs. B23 & B24 in Appendix B).

3.5. Governmental involvement

The respondents were much influenced by the community or local leaders recommendation on new kinds of pesticides compared to governmental channel such TV, newspapers, radios telling about pesticides are harmful to the environment (Table 6 and Figs. B25–B27 in Appendix B).

The rice growers and the respondents from the North region did not believe the suggestions of technical staff for selecting and using pesticides, and the governmental information that a pesticide is harmful to the environment is true and not an overstatement (Table 6 and Fig. B28 in Appendix B). The respondents from the South region to a large extent trusted the recommendations of pesticides by village leaders and neighbors (Table 6 and Fig. B30 in Appendix B).

3.6. Factors affecting the PB of pesticide use

Based on the method of regressing the PBa (here 'a' stand for average of the PB questions responses) on explanatory variables in the whole data set, we obtained the results given in Table 7 under the heading 'Aggregate'. The explanatory variables listed in the lower rows are the indices for each factor obtained as averages of the questions corresponding to those factors. These are KPUa, ARa, TRa, AGa, TGa and PCa. In addition to this regression model we also in another regression model included crops types and regions as explanatory variables shown in the same table in the last column. In none of the regression models, the explanatory variables age, family size, farm size and income showed any significant influence on PB indices. However, both crops types and regions showed significant influences on PB indices (Table 7). The rice growers increased the PB index while vegetables grower decreased compared to mixed crop growers. Also, the South-West region increased the PB index and the South region decreased index compared to South-East and North regions. In the first of these regression models, there were significant influenced from KPU, TR, TG and PC. Increasing the TG values decreased the PB index. In the second regression model, where we have accounted for crop types and regions, the influence from the factors were very similar, however there is also influence from AR and AG but not from TG (Table 7). The last results can be explained by strong correlation between AG and TG.

To separate the different groups of farmers (crop growers) and different regions, we used separate regression models of PB index on the demographic and explanatory variables, results of which are showed in Table 8. Among the demographic variables, age group influenced in South and income influenced in South-West region. The lowest age group decreased the PB index in the South, and the lowest income group increased the PB index in the South-West region (Table 8).

The influence from the PC factor is present in all the groups. The influence from the KPU factor is present in all groups except in North, influenced from AR factor is present only in the mixed crop growers and the other factors are sporadically influencing in different groups (Table 8).

To take into account simultaneous outcome of all the factors such as KPU, AR, TR, AG, TG, PC and PB resulting from the individual farmers responses, we modeled instead a structural relation among the factors shown in Fig. 4A for the 'Aggregate' of the data set. From the Fig. 4A is shown the positive significant influences from the PC and KPU factors and negative significance influences from the AG and TR factors while TG and AR are not significant. The TR factor obtained in this case was mainly related to the second question (TR2

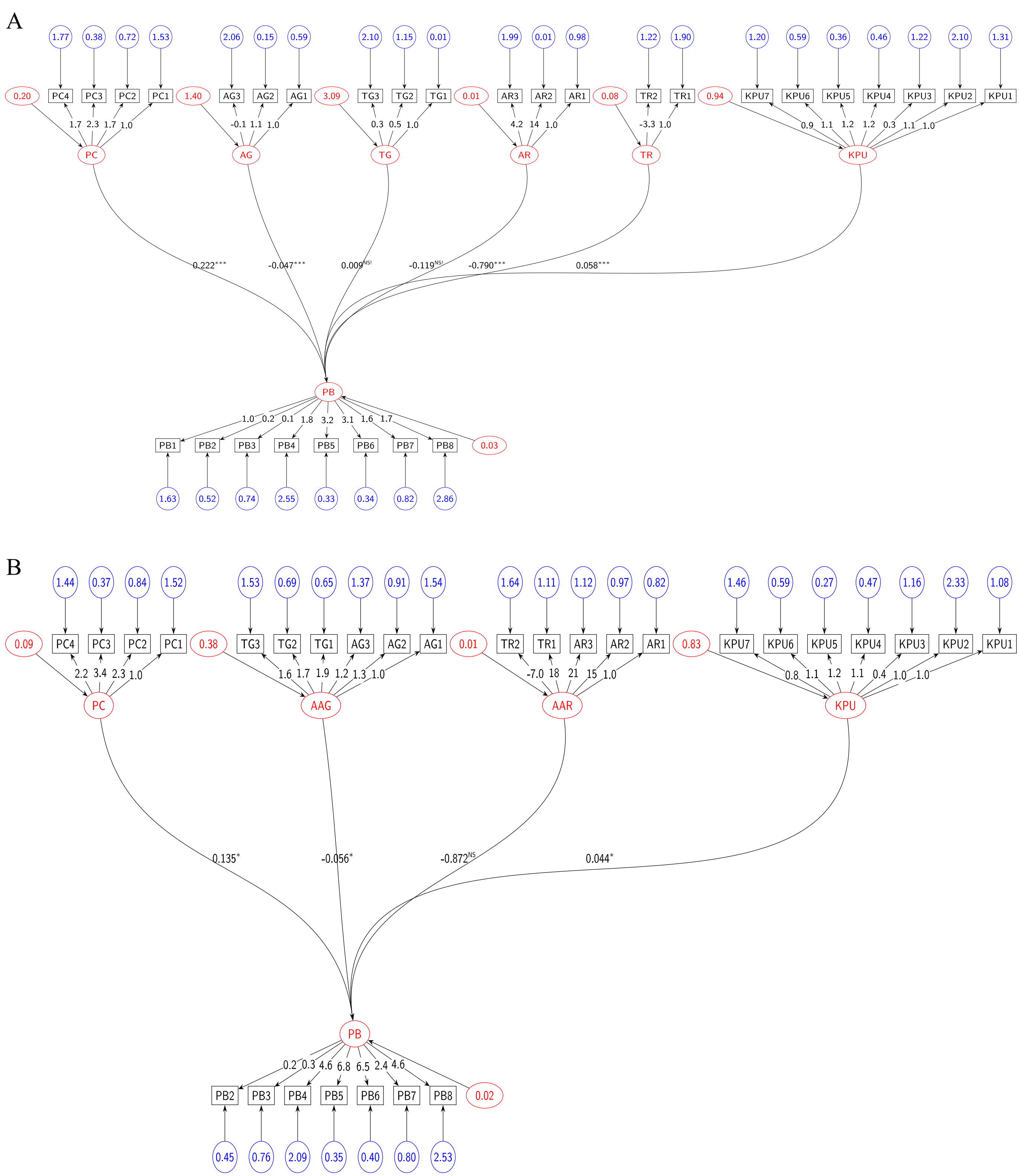

Fig. 4. Path analysis of the factors affecting the protective behaviors of pesticide use among different farmers A. 'Aggregate'; B. Rice; C. Vegetables; D. Mixed crops growers.

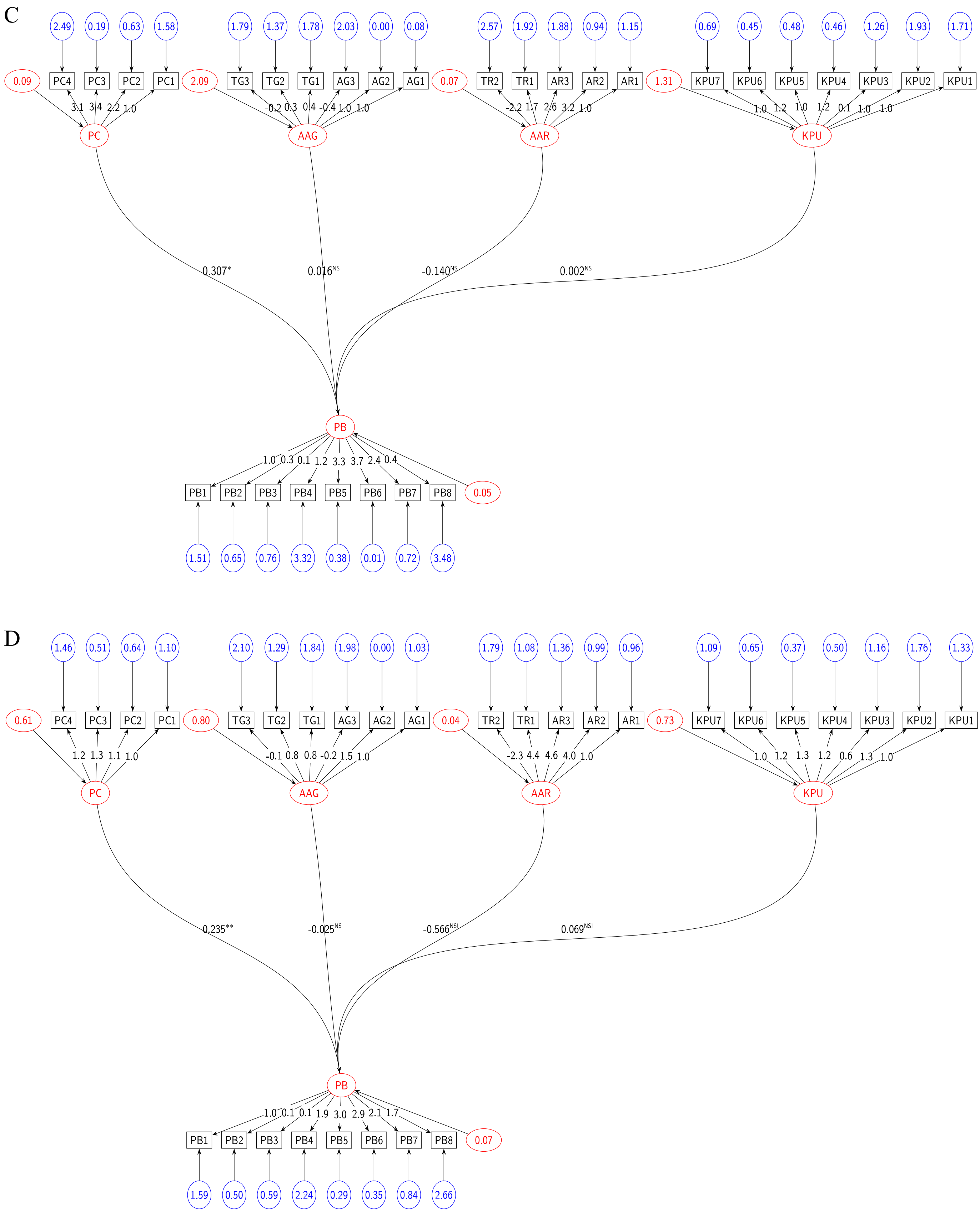

Fig. 4 (*continued*).

in the Fig. 4A) in a negative way. This implied that the PB co-varied with TR2 in a positive way. All these factors differ from the previously calculated averages of questions responses such as KPUa etc.

Here the factor scores are calculated to obtain uncorrelated factors using R package such as 'lavaan' to see the pure influence from the factors. The significance levels shown in the figures are those

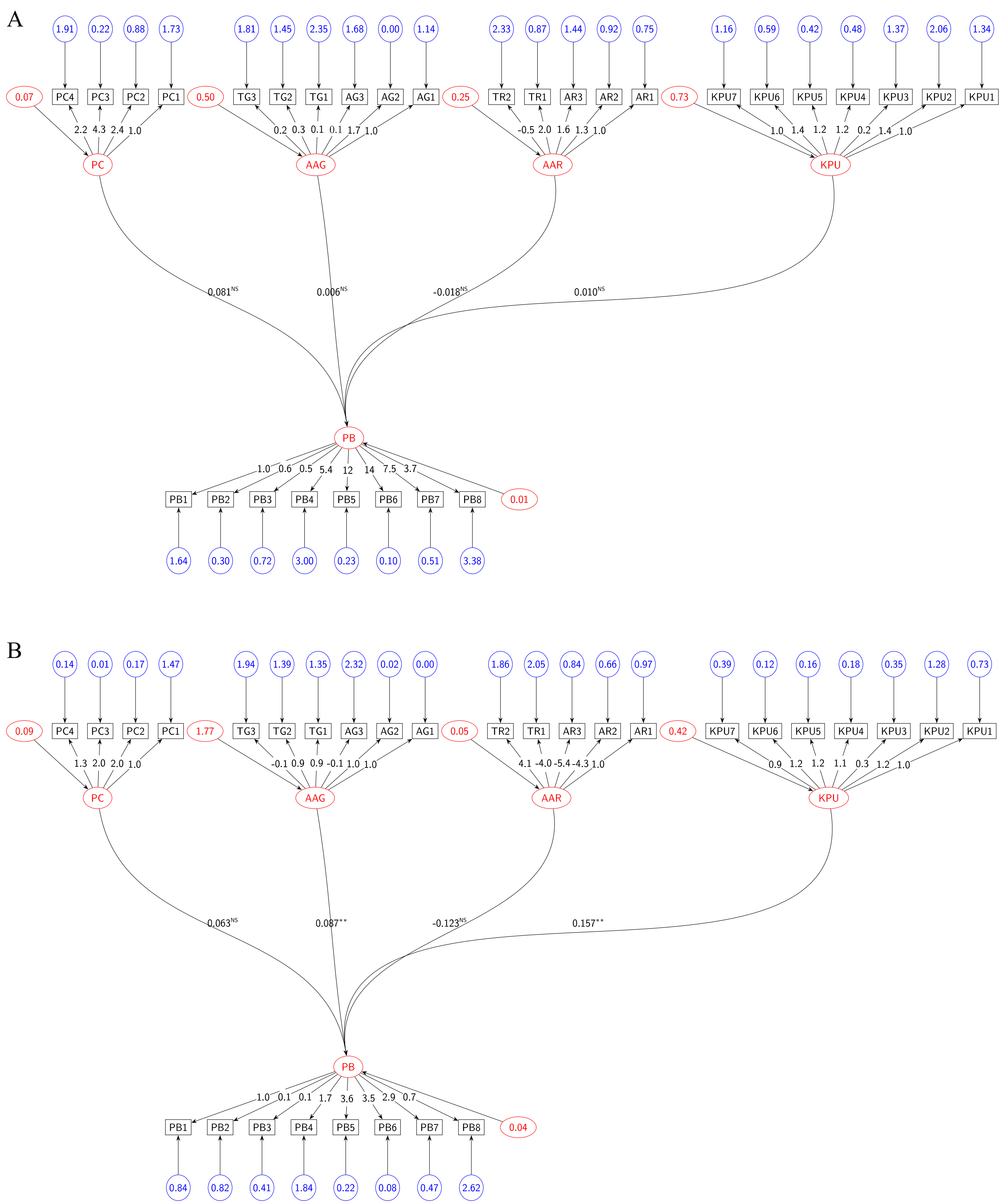

Fig. 5. Path analysis of the factors affecting the protective behaviors of pesticide use among different farmers in different regions A. South-West; B. South-East; C. North; D. South.

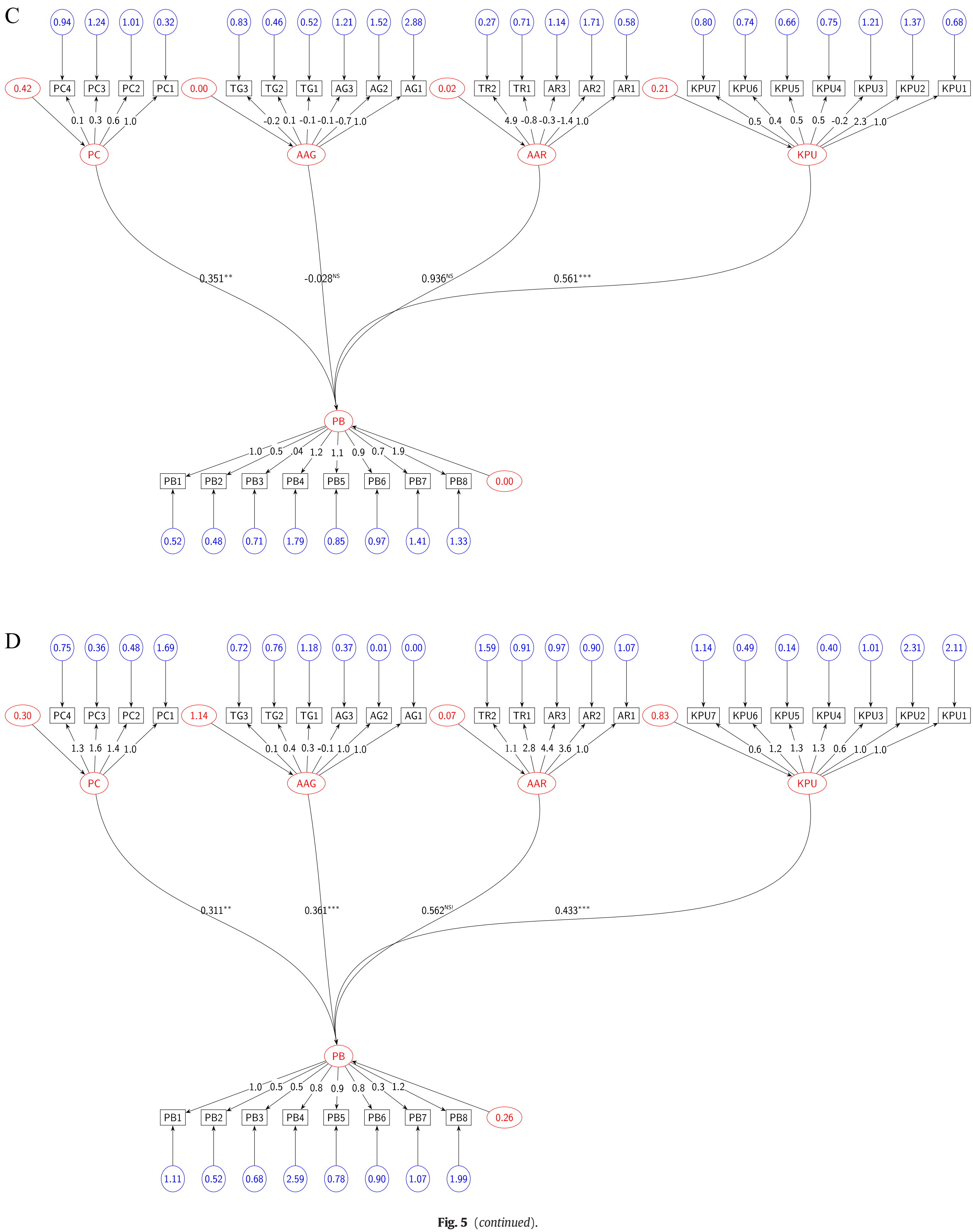

Fig. 5 (*continued*).

obtained under certain assumptions on the measurement scales and distributional properties of the underlying factors. For the Likert-scale measurements obtained in our study these assumptions are not fully met, but we still consider the results obtained, and presented in the figures, to be important indications of relations found – yet on a somewhat different level of significance.

We also modeled the simultaneous factor relations for each of the different crop types groups and respondents from different regions.

3.6.1. Crop types

For each of different groups, we consider four endogenous factors such as KPU, PC, AAR (AR + TR), AAG (AG + TG) to be able to estimate influence and uncertainty in these reduced sample size groups.

For rice growers, we have positive influence on PB factor score from PC and KPU but negative from AAG factor, Fig. 4B. For vegetable growers, we have positive influence on PB factor score from PC factor, Fig. 4C. For mixed crop growers, positive influence on PB factor score from PC factor, Fig. 4D.

3.6.2. Regions

Farmers from South-West do not have significant influence on PB factor score from the other factors, Fig. 5A. The respondents from South-East have positive influence on PB factor score from AAG and KPU factor, Fig. 5B. Farmers from North have positive influence on PB factor score from PC and KPU factor, Fig. 5C. The respondents from South have positive influence on PB factor score from PC, AAG and KPU factor, Fig. 5D.

3.7. Response patterns on research questions among farmers

Despite the rather simple factor model, including only two factors, giving a communality of 37% of the total variation, the factor scores obtained from this description were quite distinct for the particular region to which the farmer belong, and to a lesser extent to the crops types that the farmer mainly cultivate.

Fig. 6 shows the answering patterns of individual farmers on the two factors across different regions. It is worth noting that there are distinct patterns in terms of knowledge, perception and pesticide use behavior for farmland practice depending on regions (Fig. 6). The North region, the South region, and the South-West region all showed concentrated patterns; the North region having negative large values of factor 1, the South-East having large values on factor 1, and South region having large values of factor 2. The South-West region farmers, in contrast, occurs for large values on both factor 1 and factor 2, as well as for negative large values on both factor 1 and factor 2. This indicated rather consistent answering patterns within the particular region, but characteristic different answering patterns between different regions.

In a similar manner Fig. 7 shows the answering patterns divided into the type of crop grower. Vegetables growers show answering patterns corresponding to large values of factor 1, or large values of factor 2. This distinguish them from Rice growers and Mixed crop growers which both can be found over the whole range of the two factors score values, but to some extent are dominating the lower half of factor 1 score values.

Fig. 8 illustrates the factor loading on the two factors for the individual items in the questionnaire. Questionnaire items that have high loadings on factor 1 (only) are for example. 'Pesticide_products_harmful' (Pesticides are very harmful to agricultural products), 'Pesticides_Human' (Pesticides are associated with current human illness), 'Environment_effected' (The environment is highly affected by

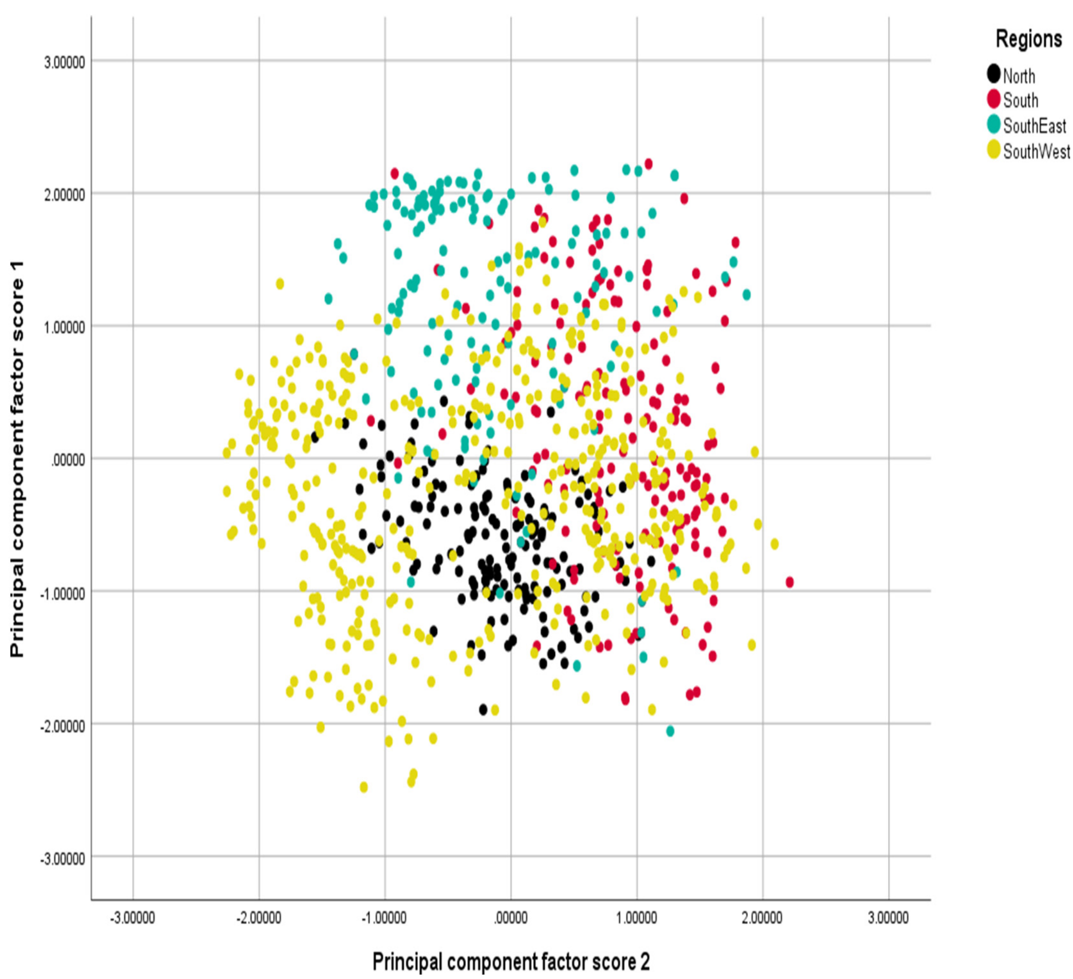

Fig. 6. Factor scores for individual farmers illustrated by regions.

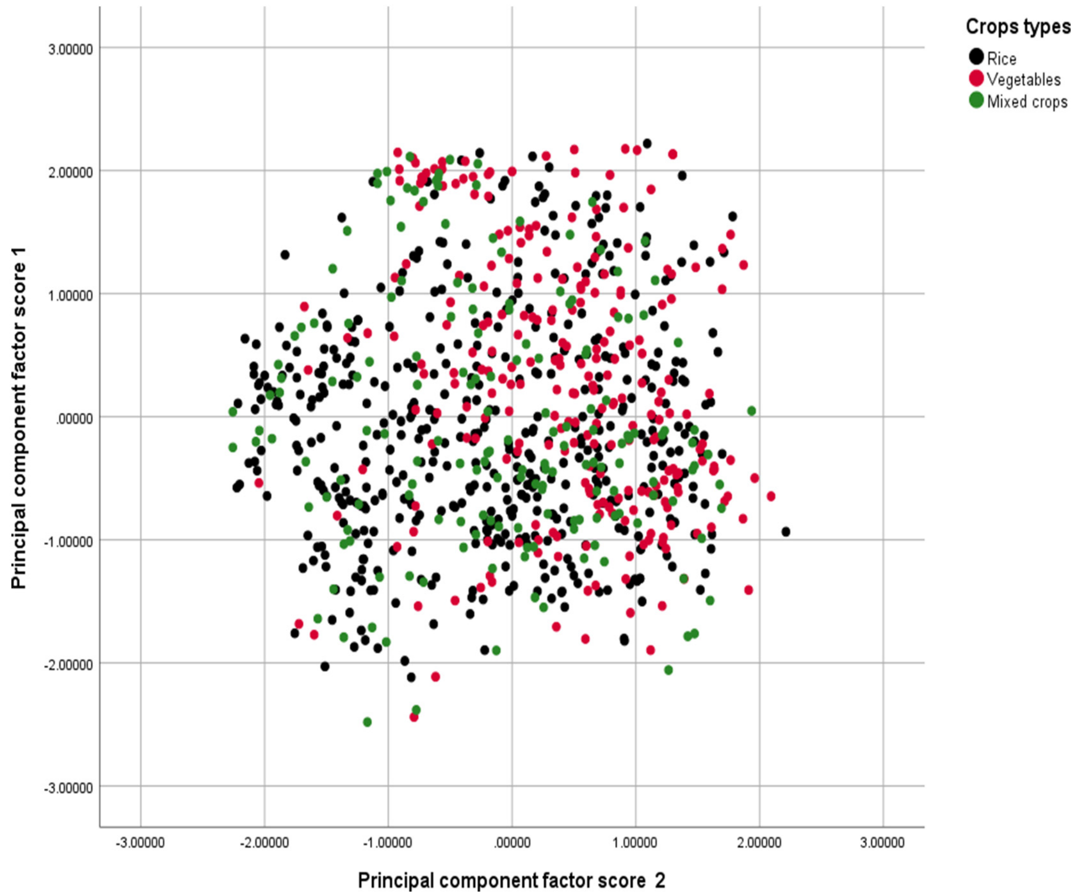

Fig. 7. Factor scores for individual farmers illustrated by crops types.

pesticide use), 'Local_government_tells_pesticides_e.g._TV_newspaper' (The local government tells us that pesticides are harmful to environment through e.g. TV, Newspaper, radios) and 'Know_body_effects' (Know pesticide effects on the body). Therefore, this indicated that factor 1 summarized largely properties of KPU and trust of local government information.

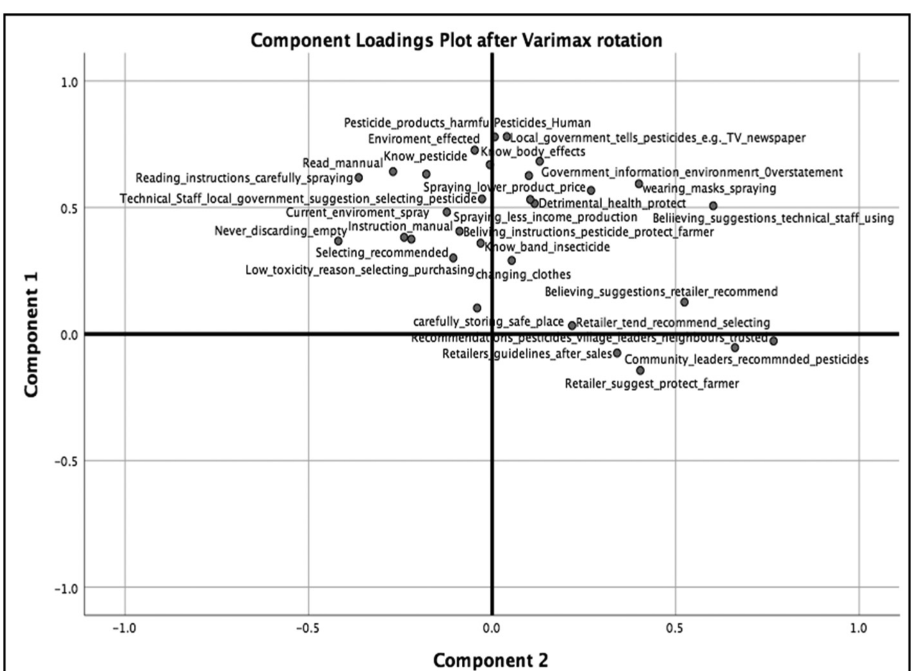

Fig. 8. Component plot of the factor loadings of the two-component factors model after Varimax rotation.

Items that have high loadings on factor 2 (only) include 'Recommendations_pesticides_village leaders_neighbours_trusted' (The recommendations of pesticides by village leaders and neighbors can be trusted), 'Community_leaders_recommended_pesticides' (Community leaders often recommend new kinds of pesticides), 'Believing_suggestions_retailer_recommend' (Believing the suggestions of retailers when they recommend pesticides), 'Retailer_suggest_protect_farmer' (Retailers suggest ways to protect farmers when using the pesticides). Other questionnaire items have high loadings on both factors.

4. Discussion

Agro-chemicals e.g. use of pesticides and fertilizers are common practices in agriculture particularly in intensive and small farm holders such as in Bangladesh, a densely populated country with high agricultural economy dependent society (BBS, 2016; BBS, 2020b; WB, 2016a). The present study is mostly related to crop-based (rice, vegetables, mixed crops), intensive, conventional as well as manual farming systems. So, knowledge about perceptions of pesticide use, pesticide harmfulness to the environment and influence of pesticide use on other issues are of particular importance in such context.

The present study showed that most of the demographic variables did not show any influence on the protective behaviors (PBs) of farmers except the age and the income; both variables influenced differently in different regions. Young farmers in South region were more reluctant to PBs or use personal protective equipments (PPEs) compared to other age groups. Akter et al. (2018) also reported that education, age, training received and types of involvement in agriculture have strongly influenced on PBs of 101 sampled vegetables farmers in one area (e.g. Jamalpur district) of Bangladesh whereas we found only age, income and regional effect on farmers PBs. However, Damalas and Hashemi (2010) showed that young farmers in Greece had more positive attitudes towards pesticide PBs than older farmers. Also, low income farmers in South-West were more prone to PBs (PPEs) than other higher income groups of farmers. These findings however, were not found in the other regions.

Our study showed that the PBs of farmers were mainly affected by different perception and attitude factors such as level of knowledge, perceptions of the consequences of their behavior, and actions of the government and pesticide retailers. Similarly, Fan et al. (2015) found that the PBs of farmers were mostly affected by age, education, level of knowledge, perceptions of the consequences of their behavior, and actions of the government and pesticide retailers. Stadlinger et al. (2011) also showed that over 50% of Tanzanian farmers often mixed pesticides with their bare hands because of their low level of knowledge and higher rate of illiteracy. In a high income agricultural setting like North-Eastern Italy, more than 90% pesticide applicators used PPEs i.e. gloves, masks and post-spraying personal hygiene practices (Riccò et al., 2018). On the other hand, knowledge level was adequate among farmers but this did not reflect in their practice in South Karnataka, India (Satya Sai et al., 2019). Calliera and L'Astorina (2018) emphasized the importance of a flexible education system and training tools in supporting to knowledge system perception-oriented, context-specific, more participative that involve different factors and different types of knowledge.

We found that the PBs of farmers was greatly influenced by different crops growers and the different regions of the study area. This finding also agrees with the findings of other studies, for example Shammi et al. (2020) and Ahmed et al. (2011). Ahmed et al. (2011) showed that different farmer groups and their neighbors differed in attitude and perception of pesticide use in the different regions, such as Skåne and Mälardalen of Sweden. The present study was conducted in an intensive agriculture and among small farm holders in Bangladesh but still showing such influences by the regions in Bangladesh and this has also been reported by Shammi et al. (2020). Yang et al. (2014) also found that two different regions in China showed different behavior to the exposed of risks from the pesticide use.

Our study indicated that vegetable farmers were more educated and had sufficient farming knowledge compared to other crop growers. However, mixed crop growers had little bit more income compared to other crops growers. Chadha and Oluoch (2003) found that the annual income by over 30% from vegetables and fruits growers in low-income countries, on the other hand, the amounts of pesticides used are three times higher for vegetable and fruit crops than for grain crops (Van Hoi et al., 2009). In Bangladesh, the richer farmers used pesticide more frequently as compared to small and medium-holders farmers with extremely and highly hazardous category pesticides as classified by World Health Organization and at high risk under the pesticides contamination to the environment and farmers health (Islam et al., 2016; Parveen and Nakagoshi, 2001).

Regardless of the instruction by the local government through different media, the respondents trusted the instruction manual very likely even though they showed lower trust to the local government. However, Fan et al. (2015) indicated that the actions of pesticide retailers and authorities play an important role by providing information and guidance on pesticide selection, awareness and behavior of farmers, even if the pesticide retailer is the only entity who can provide information to farmers who lack information and have low educational levels. Therefore, Yang et al. (2014) and Fan et al. (2015) emphasized the need for effective educational and supervision programs for pesticide retailers. Calliera and L'Astorina (2018) suggested that the diffusion of a culture of prevention and anticipation as the most effective tools to management of risks on health and the environment; and communication and social interaction of sharing of experience and transmitting the information.

The present study indicated that vegetables growers and farmers from the South region received more help from community leaders compared to other growers and other regions. On the other hand, farmers from the South-East region received more help from technical staff and local government personnel through media (e.g. TV). Similar findings are also described in other studies (e.g. Fan et al., 2015; Midega et al., 2012; Togbe et al., 2012). Fan et al. (2015) found that only vegetable farmers received help from the technical staff, although the degree of assistance was inadequate. Farmers generally did not receive any extension services on cotton pest management in Kenya (Midega et al., 2012). They indicated a need to develop an IPM approach based on farmers' practice of mixed cropping through a multidisciplinary approach; to enhance farmers' knowledge acquisition and sharing on pests of cotton and their management.

As many as one third of the respondents which have high believe in the instructions of retailers on pesticide use and protection simultaneously also very likely follow the prescription by DAE on the use of pesticides. Rios-Gonzalez et al. (2013) found that farmers often rejected and questioned technical staff and pesticide retailers due to differences in perceived economic risks and interests among farmers, government services like DAE staffs and pesticide retailers. Jin et al. (2015), however, found that the information provided by pesticide retailers varied from famers to farmers depending on their familiarity with the farmers. In Bangladesh, farmers mostly sought advice on pesticide use from pesticide dealers or retailers and a very few farmers contacted government extension workers for this purpose (Rahaman et al., 2018).

Our study showed that vegetable growers, respondents from different regions (e.g. South-East and South regions) trusted the information given by technical staff and governmental information i.e. they believed the providing information and the trust of farmers depends mainly on the information they receive taking into account (Guivant, 2003). Togbe et al. (2012) also mentioned that socio-organizational arrangement for the management of pesticide use and the setting up of a mechanism for farmers' empowerment increased the trust on information.

Yang et al. (2014) indicated that the information provided by pesticide retailers to farmers always varies with the variation of different factors, for example, levels of the pesticide retailers market such as, family stores or village, township and county shops and ability to access information sources e.g. upstream retailers, internet, instruction, or training and different information delivery methods e.g. oral, written and product labels.

Pesticide risk is a function of toxicity and exposure as well as dose and pesticide exposure depends on how farmers handle pesticides for example, wearing PPEs during spraying, following instruction about sanitation method after spraying, storage, transporting, mixing, loading etc. Use of pesticide is a main challenge to accomplish sustainable agriculture; alternative technologies e.g. integrated pest management (IPM) strategies, good agricultural practice (GAP) and organic farming without causing harm to the yield to promote sustainable agriculture and also strengthening the production system with respect to environmental health risks, enforcing better training for public health workers, agricultural extensions regarding the safe use of pesticides and its management and amend current legislation (Schreinemacchers et al., 2016; Kabir and Rainis, 2014; Shammi et al., 2020). The lack of a uniform system designed specifically for pesticide management at the end-user level (e.g. farmers' and retailers' level) is one of the main obstacles to effective pesticide regulation in Bangladesh which has debilitated the enforcement of existing regulations and resulting in misuse or overuse of pesticides, and as a result, increased environmental contamination and human exposure (Shammi et al., 2020). Government needs to amend rules e.g. "The Pesticides (Amendment) Act, 2009" and "Environmental Conservation Act Amendment 2010" and integrate a special section for the end-user of pesticides like farmers, retailers mentioning proper methods of pesticide storing, preparation, application, and container disposal to protect public health and environment; also, needs to develop a flexible education system and training tools in supporting to knowledge system perception-oriented, context-specific, more participative that involve different factors and different types of knowledge (Calliera and L'Astorina, 2018).

5. Conclusion

This study indicated that PBs were largely affected by the type of crops growers and the locations/regions. Inadequate PBs of farmers in pesticide use was mainly due to lack of knowledge, ineffective actions of the government and pesticide retailers. Vegetable farmers had comparatively higher levels of knowledge than other crops growers and also had higher income, however perhaps use more pesticides to guarantee high crop yields and income. There is a need for continuous pesticide safety education along with training to the farmers regarding PBs i.e. use of personal protective devices, personal hygiene and sanitation practices during and after application of pesticides. As a better knowledge of pesticide-related risks was a significant predictor to reduce the risk, our results stress that improving awareness and promoting safe use of pesticide may improve the health of farmers. Furthermore, a large gap of trust existed among farmers, pesticide retailers, and the government, which contributed to farmers' inadequate PBs. The supervisory mechanism and environmental monitoring systems for pesticides need to be strengthened and the nation scale study on safety use of pesticide and its risk on environment and human health need to also be evaluated. All stakeholders, including governmental agencies, producers, retailers, and farmers, need unite to address the risks from the use of pesticides for farmers and the environment.

The present study approach, to consider many different regions, different types of crops growers, socio-economical features e.g. farm size, family members, education, age, income etc. and risk perception and attitude, have given insight and help farmers to improve their practices in PPEs or PBs in pesticide use on farms and to make suitable options in order to reduce environmental and human risk, without sacrificing the food quality, sustainability and the profitability of agricultural production.

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CRediT authorship contribution statement

Md. Panna Ali: Project administration, Resources, Methodology, Data curation, Formal analysis, Writing - original draft, Writing - review & editing. **Mir Md. Muniruzzaman Kabir:** Resources, Methodology, Data curation, Writing - review & editing. **Sheikh Shamiul Haque:** Methodology, Project administration, Writing - review & editing. **Xinghu Qin:** Formal analysis, Writing - review & editing. **Sultana Nasrin:** Formal analysis, Writing - original draft, Writing - review & editing. **Douglas Landis:** Project administration, Writing - review & editing. **Björn Holmquist:** Formal analysis, Writing - original draft, Writing - review & editing. **Nur Ahmed:** Formal analysis, Writing - original draft, Writing - review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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