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RESEARCH ARTICLE

Endosulfan residues and farmers' replacement behaviors of endosulfan in the north-west inland cotton region

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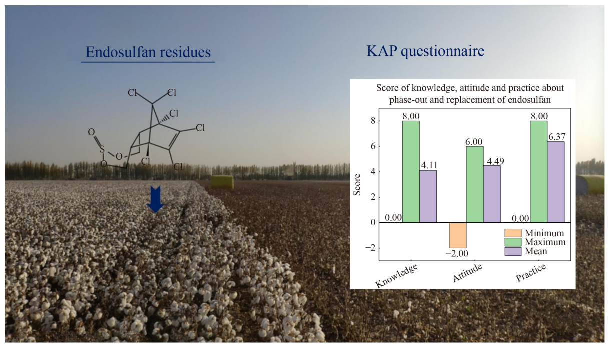
HIGHLIGHTS

- The situation of endosulfan residues in cotton fields were assessed.
- A KAP survey was carried out for cotton farmers.
- Endosulfan sulfate was the main endosulfan residue in the soil.
- Cotton farmers scored low on knowledge about the phase-out of endosulfan.

GRAPHIC ABSTRACT



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ABSTRACT

We assessed the situation of endosulfan residues in cotton fields after the endosulfan ban came into effect and the current knowledge, attitude, and practice (KAP) of cotton farmers on the phase-out of endosulfan and the application of alternative technologies. Topsoil samples (n = 91) of cotton fields were collected from the major cotton-producing areas in China, namely the north-west inland cotton region, and the endosulfan residues were analyzed. A KAP survey was carried out for cotton farmers, and 291 questionnaires were distributed. The influences of gender, age, education background, cotton planting years, publicity and training, income sources, and other factors on cotton farmers' KAP were analyzed. The results showed that endosulfan sulfate was the main endosulfan residue in the soil, followed by β-endosulfan and α-endosulfan, the average residual contents were 0.569, 0.139, and 0.060 μg/kg, respectively. The results of the KAP study showed that cotton farmers scored low on knowledge about the phase-out of endosulfan and the application of alternative technologies but high on attitude and practice. The number of family members, years of cotton planting, age, and the cotton-planting area had different degrees of influence on KAP scores. The training could significantly improve the KAP scores of cotton farmers; training should be more targeted and designed reasonably for key groups, such as men and the population under 30, followed by training them to use pesticides safely. For large-scale cotton growers, training should focus on green prevention and control technologies.

1 Introduction

Cotton is a natural fiber and a major global cash crop occupying a unique position in international economic development. Cotton is not only important for the livelihood of many farmers but also for agricultural products with the longest industrial chain, thus playing an

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important role in the economy of the cotton-producing countries (Hulsekemp et al., 2014). However, due to its long production cycle, cotton is easily affected by pests and diseases, which can cause a 15%–20% yearly yield loss, with as high as 50% loss in some years (Chen et al., 2020). The prevention and control of cotton pests and diseases largely depend on chemical pesticides.

Endosulfan is a typical broad-spectrum organochlorine pesticide widely used in agricultural production for the past 30 years (Jia et al., 2009). Endosulfan has been used in China to control cotton pests and diseases with good prevention and control effects. Generally, the ratio of α-endosulfan (α-ES) to β-endosulfan (β-ES) in industrial endosulfan is about 7:3, in which the half-life of α-ES is 7–75 d while β-ES is 33–376 d (Weber et al., 2010); endosulfan sulfate (ES-sulfate) is the major degradation product of endosulfan. Compared with its parent compound, ES-sulfate is more mobile and more likely to enter water bodies with surface runoff or penetrate deeper into soil and groundwater. Endosulfan was included in Annex A (elimination category) of the Stockholm Convention on Persistent Organic Pollutants in 2011 because of its long half-life in the environment (UNEP, 2011). China has banned endosulfan production, circulation, use, import, and export since March 26th, 2019, officially declaring the complete elimination and prohibition in China.

North-western China is one of the main cotton-producing areas. In 2020, the cotton planting area in this region reached 2,528,500 hm^2, accounting for 79.47% of the national cotton planting area, and the cotton yield reached 5,191,000 t, accounting for 87.8% of the national cotton yield (National Bureau of Statistics, 2020). Historically, the use of endosulfan has been concentrated in this region, which accounts for 90% of the total use of endosulfan in China. Although pesticides effectively control crop diseases and pests, they can also have adverse effects due to their inappropriate application (Huang et al., 2020; Guo et al., 2022; Li et al., 2023). For example, excessive application of pesticides leads to serious water, soil, and air pollution when pesticide residues enter water, soil, and air (Sharma et al., 2019). Moreover, excessive pesticide application can lead to food pesticide residues, which can cause serious health problems. (Hassaan and El Nemr, 2020) In addition to these adverse effects, pesticide application may harm human health and damage biodiversity (Shahid and Khan, 2022). Farmers play an important role in agricultural production and are an important factor influencing whether or not pesticide bans can be implemented (Huang et al., 2020; Li et al., 2023).

To understand the situation of endosulfan residues in cotton fields after endosulfan is banned and the current status of knowledge, attitude, and practice (KAP) of cotton farmers on the phase-out of endosulfan and the application of alternative technologies, the endosulfan residue analysis of topsoil samples of cotton fields was carried out in the main cotton producing area in China, namely the north-west inland cotton region. A KAP survey was carried out for cotton farmers to determine the situation and ecological risks of endosulfan residues in cotton fields in China and clarify the influences of gender, age, education background, cotton planting years, publicity and training, income sources, and other factors on cotton farmers' knowledge, attitude, and practice about endosulfan replacement and phase-out. It is expected to provide a reference for government departments to make decisions on prohibition and replacement measures for pesticide persistent organic pollutants (POPs) in the future and for other developing countries.

2 Materials and methods

2.1 Collection and treatment of soil samples

Based on the cotton planting area, cotton fields in the north-western inland region of China were selected for research. In 2020 and 2021, 91 topsoil samples were collected from a cotton-planting region. A single diagonal 7-point sampling method was adopted for sample collection according to HJ/T166-2004 and NY/T395-2012. When sampling, the top 1–2 cm of material on the soil surface were scraped off, and then 0–20 cm soil columns were collected vertically downward with a soil drill, transferred into a sampling bag, and seven soil samples from each sampling point were mixed and packed into a clean sealed bag with a total amount of not less than 1.0 kg. The bags were refrigerated and transported to the laboratory for further use. The specific analytical and testing methods followed those used by Zhang et al. (2022). A laboratory blank was routinely performed, and the values were lower than the detection limit of the method used. The recoveries of α-ES, β-ES and ES-sulfate were between 97.8% and 114.1% with a relative standard deviation < 15%. No target analyte was detected in the method blank and sample blank.

2.2 Questionnaire contents and scoring criteria

2.2.1 Questionnaire contents

Based on the reference of relevant laws, regulations, standards, and other documents, a set of KAP questionnaires on endosulfan residues and cotton farmers' replacement practices in the north-west inland cotton region was developed after self-design, expert review, and approval, as well as iterated modifications. (Sharafi et al. 2018; Ahmad et al. 2019) The questionnaire was divided into four parts: basic information on participants, knowledge, attitudes, and practices regarding endosulfan phase-out and replacement. The basic information of participants included gender, age, education level, location, the permanent resident population of the family, whether they are the main labor force of cotton planting in the family, whether they joined the cooperative, cotton-planting area, cotton-planting years, and whether cotton planting is the main family income source. The questions in the knowledge part include type, toxicity, objects of prevention and control, shelf life, application times, application methods, and the current situation of endosulfan pesticides. The questions in the attitude section include the influence of endosulfan-related bans on cotton pest prevention control, views on methods such as the use of biopesticides, willingness to participate in information and technical training on pesticide prohibition and restriction, and the participation of relevant government departments in publicizing and organizing specialized training on green prevention and control. The practice questions focused on whether or not the participants chose green prevention and control measures, whether or not they recommended them to others, and whether or not they carefully read the instructions for pesticide use and applied the pesticide in strict accordance with the recommended dosage.

2.2.2 Scoring criteria

Basic information of participants was collected but not scored in the questionnaire. The total score on the questionnaire was 46. There were eight multiple-choice questions in the knowledge section. Two choices were provided for each question, with a score of 1 for a correct answer and 0 for an incorrect selection. There were six questions in the attitude section; for a question with two choices, the correct answer scored 1, while a wrong answer scored 0. Questions 20 and 23 had three options; the correct answer scored 1, an incorrect answer scored −1, and 0 for uncertainty or lack of clarity. There were four questions in the practice part, with three choices for each question; negative choices, such as "No" and "It's not clear," received a score of 0, neutral choices received 1, and positive choices, such as "Yes" and "Good," received 2.

2.3 Statistical analysis

Data were analyzed with SPSS 25.0 (IBM Corp. Released 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk, NY: IBM Corp.), and the significance level was $p < 0.05$. Enumeration data were described as frequency and composition ratio, and measurement data were expressed as mean ± standard deviation (x ± s). According to the data type, a statistical comparison was made using the *t*-test and one way analysis of variance (ANOVA). The Pearson correlation coefficient was used to analyze the correlation between endosulfan phase-out, replacement, and related KAP.

3 Results and discussion

3.1 Endosulfan residues in cotton field

Endosulfan residues were detected in the north-west inland cotton region of China, and the detection rates of α-ES, β-ES, and ES-sulfate were 49.5%, 60.4%, and 71.4%, respectively. In the topsoil of cotton fields, the α-ES content ranged from N.D. to 0.655 μg/kg, with a mean of 0.060 μg/kg; the β-ES content was N.D. ~1.197 μg/kg, with a mean of 0.139 μg/kg; the ES-sulfate content was N.D. ~6.170 μg/kg, with a mean of 0.569 μg/kg; the ∑ESs content was N.D. ~8.022 μg/kg, with a mean of 0.796 μg/kg (Table 1). The main residual component was ES-sulfate, followed by β-ES and then α-ES, mainly because α-ES is more likely to evaporate into the atmosphere. Therefore, the concentration of β-ES in the soil is higher than that of α-ES, and the half-life of ES-sulfate is longer than that of α-ES and β-ES.

Compared with previous studies from other regions and countries, the concentration of endosulfan residues in this study was higher than that in the agricultural land of Shanghai, China. However it was lower than that in the Daiyunshan region of Fujian, Pearl River Delta, Wuhan, and Huizhou of China, Campania of Italy, Himalayan region of India, Punjab region of Pakistan, and Kathmandu region of Nepal (Table 2).

Industrial endosulfan consists of α-ES and β-ES in a ratio of 7:3, with a specific value of 2.33. Endosulfan degrades at different rates in different types of soil, but α-ES usually degrades faster than β-ES in soil, so the α/β ratio can be used to judge whether the residues come from historical use or recent input. It is generally believed

Table 1 Basic statistical parameters of endosulfan residues in cotton field soil (n = 91, μg/kg)

Compound	Mean	SD	GM	Min	Max	Percentiles				DF(%)
						P25	P50	P75	P90	
α-ES	0.060	0.103	0.021	N.D.	0.655	N.D.	N.D.	0.074	0.164	49.5
β-ES	0.139	0.216	0.050	N.D.	1.197	N.D.	0.061	0.179	0.237	60.4
ES-sulfate	0.569	0.991	0.151	N.D.	6.170	N.D.	0.189	0.707	0.698	71.4
∑ESs	0.769	1.294	0.260	N.D.	8.022	0.072	0.274	0.914	1.864	83.5

∑ESs = α-ES + β-ES + ES-sulfate.

Table 2 Comparison of endosulfan residues in soil from different region and countries (μg/kg)

Survey region	Year	α-ES	β-ES	ES-sulfate	∑ESs	References
North-west inland cotton region, China	2020	0.142 ± 0.123	0.281 ± 0.257	0.828 ± 1.155	0.946 ± 1.518	This research
Daiyunshan region of Fujian, China	2009	0.81 ± 1.78	2.50 ± 9.05	6.93 ± 27.33	–	Qu et al. (2013)
Pearl River Delta, China	2009	0.19 ± 1.74	1.11 ± 5.45	3.81 ± 22.58		Dou & Yang (2015)
Wuhan, China	2009	0.34 ± 1.25	0.94 ± 3.89	–	1.28 ± 4.25	Zhou et al. (2013)
Huizhou City		0.56 ± 1.30	0.94 ± 1.08	10.11 ± 59.61		Ma Jin et al. (2010)
Shanghai, China	2007	0.13 ± 0.3	0.19 ± 0.54	BDL		Jiang et al. (2009)
Campania, Italy	2011	0.41 ± 0.96	0.50 ± 1.32	1.06 ± 2.60	1.96 ± 3.75	Qu et al. (2017)
Himalayan region of India		0.22 ± 0.16	0.20 ± 0.29	0.19 ± 0.28	0.62 ± 0.73	Devi et al. (2015)
Punjab, Pakistan	2011	0.33 ± 0.41	3.0 ± 1.3			Syed et al. (2013)
Kathmandu, Nepal	2015				4.21	Pokhrel et al. (2018)
Republic of Korea	2015	0.06	0.09	0.63	0.77	Kim et al. (2020)

that a ratio of less than 2.33 comes from historical use, while a ratio greater than 2.33 is considered recent (illegal) use (Yadav et al., 2016). Italian researchers found that endosulfan is illegally used in the Bari urban areas because the average ratio of α-ES to β-ES in this area is 22.44, which may be related to the control of ornamental-plant pests in urban gardens (Thiombane et al., 2018). Of the 91 sampling points in this study, the amount of α-ES residue was lower than that of β-ES residue. The value of α/β was 0–1.2 and less than 2.33 (Fig. 1), which indicated that endosulfan residues in the survey area were all from historical agricultural production and there was no new input; this also shows that the endosulfan ban has been well implemented in China. In addition, according to the results of Qu et al. (2017), the predicted no-effect concentration of the endosulfan residue was 1.71 μg/kg when using the species sensitivity distribution method (Qu et al. 2017), and only 10 of the 91 sampled plots exceeded the predicted no-effect concentration of endosulfan, indicating that most points had low ecological risk.

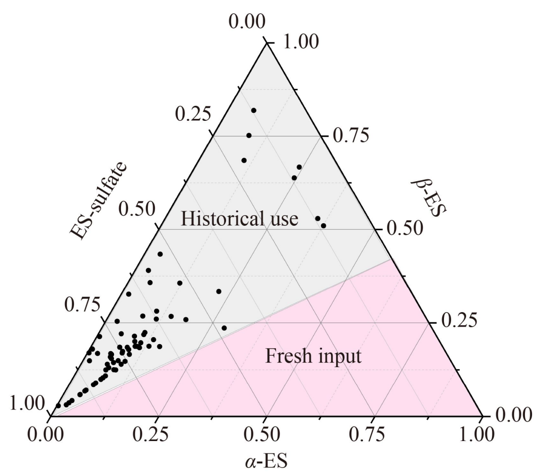

Fig. 1 The value of α/β-endosulfan.

3.2 Socio-economic charactersitics of the participants

The survey was conducted between July and August 2021. We received 291 questionnaires, and after eliminating some questionnaires with unanswered, invalid, or incomplete answers, 283 valid questionnaires were retained for analysis. The number of women respondents was 33.9% (n = 96), and men were 66.1% (n = 187). More than 90% of the participants were aged between 30 and 60, with the largest number of participants aged 41–50, accounting for 44.9% of all respondents, and the mean age was 44.67 ± 9.098. Regarding the participants' educational level, the proportion of participants with an educational background in junior middle school, senior middle school, technical secondary school, and junior college or above was 28.6%, 34.3%, and 31.4%, respectively. Only some participants (5.7%) had educational experience in primary school or below. In terms of the cotton-planting area, most participants had cotton fields of 50 mu or less (39.9%), and participants with cotton fields of 51–100 mu, 100–499 mu, and 500 mu and above accounted for 30.7%, 21.9%, and 7.4%, respectively. Regarding cotton planting years, 97.5% of the participants had been growing cotton for less than 40 years; participants growing cotton for 0–9 years, 10–19 years, and 20–29 years accounted for 32.9%, 26.5%, and 27.9%, respectively. In addition, most of the participants (65.7%) had a permanent resident population of 3–4 people in their families, and 82.3% of them were the main labor force for cotton planting in their families; more than half (52.7%) of the participants had not joined a cooperative, and 79.2% of the family's main income came from cotton planting. Basic information on the participants is presented in Fig. 2 shows the socio-demographic characteristic of participants.

3.3 KAP of endosulfan phase-out and replacement

In the KAP sections, the lowest, highest, and average

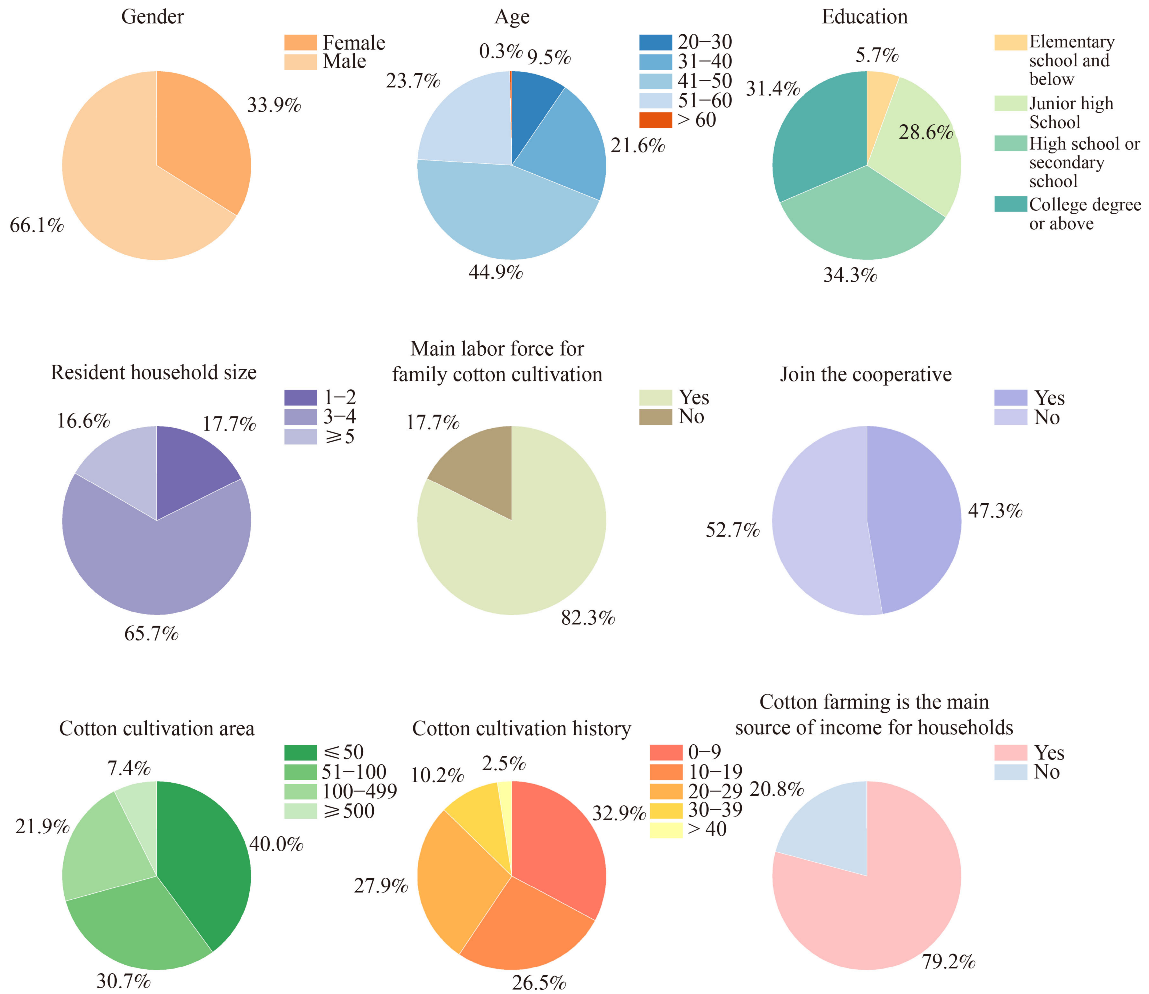

Fig. 2 The socio-demographic characteristic of participants.

scores were 0, 8, 4.11, −2, 6, 4.49, 0, 8, and 6.37, as shown in Fig. 3. Participants did not score high in the knowledge section, and the average scoring rate was 51.3%, consistent with the relatively low average score regarding pesticide-related knowledge in domestic and foreign surveys (Mou, 2016; Ahmad et al., 2019). The lowest score was on Question 14 (Q14: When endosulfan is used to prevent and control pests, how often can it be applied on crops at most per crop cycle?) The average score (average score/total score) was 23%. When judging the types of endosulfan pesticides (41.9%), toxicity (33.7%), time of application on crops per crop cycle (22.7%), and whether endosulfan can still be used today (51.2%), all scoring rates were lower than the average scoring rate of knowledge-related questions, which showed that participants did not pay enough attention to endosulfan-related knowledge. This is not conducive to forming a correct understanding of endosulfan and thus affects the formation of positive attitudes and practices toward the phase-out of endosulfan and the application of alternative technologies.

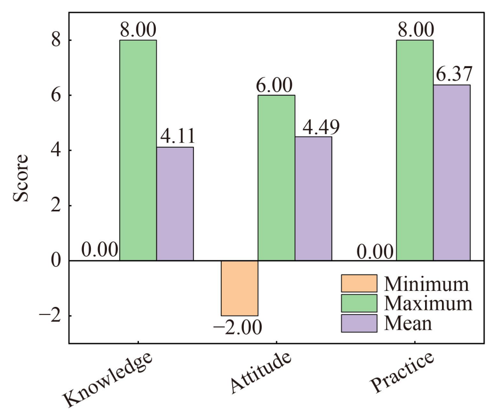

Fig. 3 The lowest, highest, and average scores for each KAP section.

Compared with the knowledge part, the participants scored relatively high in the attitude and practice parts (74.7% and 79.6%, respectively), with an average score above 70%. The lowest attitude score was for Question 18 (Q18: Will banning endosulfan affect cotton pest prevention and control?), with an average score of 40%. Only this question scored lower than the average scoring rate of the attitude-related questions, indicating that some cotton farmers still did not know the harm caused by endosulfan, and they relied heavily on endosulfan for cotton pest prevention and control in the past. In addition, 85.9% of the participants were willing to accept information and training on pesticide prohibition and restriction, and 80.2% and 88.3% of the participants were aware of the training and publicity on green prevention and control technology conducted by relevant government departments, respectively, indicating that relevant government departments could conduct training and publicity for cotton farmers through specific methods and means, and try their best to cover all types of people. 30% of participants did not read the instructions or would read the instructions but used the pesticides by experience, which showed that their awareness of safety in pesticide application needs to be further strengthened to realize the scientific and safe use of pesticides and protect users, ecology, and the environment.

Generally speaking, the overwhelming majority of participants had a positive attitude toward phasing out of endosulfan and applying alternative technologies, and they also supported endosulfan replacement practice. Subjectively, they recognized the importance of endosulfan phase-out, the application of alternative technologies, and green prevention and control. However, 14.8% of the participants said that they had never used green prevention and control measures, such as natural predators, pheromones, and lights, which also showed that there is still room for promoting green prevention and control technologies and measures in cotton-planting regions. Meanwhile, among 85.2% of participants who had used green prevention and control technologies, 71.4% rated green prevention and control technology as effective; among the participants who recognized the positive effect of green prevention and control, 96.2% would recommend natural predators, pheromones, lights, and other green prevention and control measures to others. This showed that further research and development of green prevention and control technologies are needed, and improving the actual prevention and control effect might be more conducive to promotion and recognition by cotton farmers.

3.4 Analysis of factors influencing knowledge, attitude, and practice

The survey results showed that there was no significant correlation between knowledge about endosulfan phase-out and replacement and gender, whether or not the participants were the main labor force of cotton planting in the family, whether or not they joined a cooperative, and whether or not income from cotton planting was the main source for the family (p = 0.262, p = 0.249, p = 0.111, p = 0.705) (Table 3). This indicates that in the future, all aspects should be covered by scientific popularization or publicity of endosulfan-related knowledge, and there is little utility with factors such as gender.

There were significant differences between gender in attitudes toward the phase-out of endosulfan and the application of alternative technologies (p = 0.003). The average scoring rate of men in this section was 71.0%, while that of women was 81.3%, which showed that women had a more positive attitude toward phasing out endosulfan and the application of alternative technologies. When subsequent measures are taken to improve the recognition of the phase-out of endosulfan and the application of alternative technologies, male groups should be emphasized. In addition, there were significant differences in the endosulfan replacement practice between the sexes (p = 0.002), and the average scoring rate of male (76.6%) was lower than that of female participants (85.5%). Attitude determines practice to a certain extent, and differences in approach are consistent with differences in attitudes. Although there was no significant difference between the two groups in the practice section (p = 0.054), the score of participants whose main family income did not rely on cotton planting (average score of 85.1%) was higher than that of participants whose main family income was cotton planting (average scoring rate of 78.1%), and the former was more supportive of endosulfan replacement practices, such as green prevention and control measures. This is because the advantages of green prevention and control technologies are not apparent in cost and effectiveness compared with traditional prevention and control measures. Endosulfan has no particular advantage over many alternatives in the market regarding pest prevention and control effectiveness; there are no technical obstacles to endosulfan phase-out and replacement. However, when an alternative technology for biological control was adopted, the higher cost and general use effect made it less acceptable to participants whose primary source of family income was cotton planting. Researchers have shown that a single biological control technology is not valuable for promotion; therefore, we can consider extending this technology by combining it with chemical pesticides (Tang et al., 2020).

See Table 4 for the relationship between the participant's education level, age, cotton planting area, nationality, the permanent resident population of the family, years of cotton planting, knowledge about endosulfan, attitude toward the phase-out of endosulfan, application of alternative technologies, and endosulfan replacement practices.

Regarding knowledge about endosulfan, there were significant differences between household sizes (p = 0.002). When the permanent resident population of the family was 1–2 persons, the average scoring rate of participants was the highest (78.0%); when there were five persons or more, the average scoring rate of

Table 3 T-test results of participants' basic information, knowledge, attitude and practice

Category	Variable	Classification	Mean	Standard deviation	*P* value
Knowledge	Gender	Male	4.03	1.794	0.262
		Female	4.28	1.816	
	The main labor force of cotton planting in the family	Yes	4.06	1.767	0.249
		No	4.38	1.958	
	Join a cooperative	Yes	3.93	1.691	0.111
		No	4.28	1.888	
	Cotton planting is the main income source of the family	Yes	4.13	1.851	0.705
		No	4.03	1.618	
Attitude	Gender	Male	4.27	1.908	0.002
		Female	4.91	1.487	
	The main labor force of cotton planting in the family	Yes	4.43	1.807	0.275
		No	4.74	1.759	
	Join a cooperative	Yes	4.45	1.771	0.724
		No	4.52	1.829	
	Cotton planting is the main income source of the family	Yes	4.47	1.812	0.731
		No	4.56	1.764	
Practice	Gender	Male	6.13	2.111	0.003
		Female	6.84	1.797	
	The main labor force of cotton planting in the family	Yes	6.32	2.005	0.382
		No	6.60	2.176	
	Join a cooperative	Yes	6.34	2.063	0.783
		No	6.40	2.017	
	Cotton planting is the main income source of the family	Yes	6.25	2.049	0.054
		No	6.81	1.934	

Table 4 ANOVA results of participants' basic information, knowledge, attitude and practice

Category	Variable	Classification	Average value	Standard deviation	*P* value
Knowledge	Education level	Below primary school	4.00	1.732	0.745
		Primary school	3.46	2.145	
		Junior middle school	4.10	1.704	
		Senior middle school	4.20	1.772	
		Junior college or above	4.15	1.892	
	Age	20–30	3.44	1.826	0.074
		31–40	4.02	1.893	
		41–50	4.19	1.794	
		51–60	4.37	1.659	
		More than 60	1.00	0.000	
	Cotton planting area	50 mu and below	4.17	1.977	0.179
		51–100 mu	4.23	1.654	
		100–499 mu	4.13	1.684	
		500 mu and above	3.29	1.648	
	Permanent resident population of the family	1–2	4.68	1.911	0.002
		3–4	4.14	1.728	
		5 and above	3.40	1.777	

(*Continued*)

Category	Variable	Classification	Average value	Standard deviation	*P* value
	Cotton planting years	0–9	3.82	1.983	0.039
		10–19	3.91	1.802	
		20–29	4.44	1.599	
		30-39	4.76	1.480	
		40 and above	3.86	1.864	
Attitude	Education level	Below primary school	3.67	3.215	0.510
		Primary school	4.85	1.519	
		Junior middle school	4.20	1.933	
		Senior middle school	4.53	1.768	
		Junior college or above	4.69	1.670	
	Age	20–30	3.59	1.760	0.042
		31–40	4.33	1.768	
		41–50	4.68	1.680	
		51-60	4.66	1.974	
		60 and above	3.00	0.00	
	Cotton planting area	50 mu and below	4.65	1.641	0.025
		51–100 mu	4.75	1.679	
		100–499 mu	4.02	2.068	
		500 mu and above	3.90	1.972	
	Permanent resident population of the family	1–2	5.02	1.545	0.006
		3–4	4.50	1.768	
		5 and above	3.85	2.000	
	Cotton planting years	0–9	3.92	1.979	0.003
		10–19	4.56	1.638	
		20–29	4.90	1.464	
		30–39	4.97	1.880	
		40 and above	4.57	2.507	
Practice	Education level	Below primary school	5.00	2.646	0.245
		Primary school	7.23	1.423	
		Junior middle school	6.10	2.223	
		Senior middle school	6.47	1.871	
		Junior college or above	6.43	2.066	
	Age	20–30	5.78	2.063	0.347
		31–40	6.20	2.174	
		41–50	6.44	1.983	
		51–60	6.61	1.984	
		60 and above	8.00	0.00	
	Cotton planting area	50 mu and below	6.79	1.790	0.012
		51–100 mu	6.30	1.989	
		100–499 mu	6.02	2.214	
		500 mu and above	5.48	2.502	
	Permanent resident population of the family	1–2	6.92	1.441	0.107
		3–4	6.27	2.129	
		5 and above	6.19	2.133	
	Cotton planting years	0–9	5.47	2.282	0.000
		10–19	6.69	2.013	
		20–29	6.84	1.613	
		30–39	6.90	1.520	
		40 and above	7.43	0.976	

participants was only 56.7%, which might be due to the mutual influence of family members on endosulfan-related KAP. There were also significant differences between different cotton-planting years ($p = 0.039$); when the cotton-planting years were 30–39 years, the average score was the highest, and when the cotton-planting years were less than 40 years, the average score gradually increased with an increase in the number of cotton-planting years (i.e., the working years), indicating that the more experienced cotton-planting participants knew more about endosulfan. However, with more than 40 years of experience, the average score decreased, which might be because the longer the years of cotton planting, the more participants used endosulfan based on their previous experience, and they did not understand and learn more about new pesticides and technologies. At the same time, the participants were older, so there might be a decline in their memory and learning ability. In addition, research has shown that there is a specific correlation between endosulfan-related knowledge and education level; however, this was not found in this study, which may be because the knowledge of pesticide use and pesticide information obtained by cotton farmers mostly comes from pesticide sales personnel (Fang et al., 2015). Sales personnel are rich in experience and have a better understanding of the efficacy of pesticides, so they can provide farmers with technical guidance from manufacturers and solve problems in planting, pest prevention, and protection (Lv, 2012). Therefore, training pesticide sales personnel on the safe use of pesticides can be strengthened in the future (Fang et al., 2015) to better introduce popular science concerning relevant knowledge and pesticide safety to people who use pesticides.

Second, there were significant differences in attitudes toward the phase-out of endosulfan and the application of alternative technologies among people of different ages, cotton-planting areas, permanent family populations, and cotton-planting years ($p = 0.038$, $p = 0.000$, $p = 0.010$, and $p = 0.003$, respectively). The average score of participants aged 31–60 was higher than that of < 30 and > 60. The former may lack knowledge about pesticide use and green prevention and control technologies, whereas the latter may have experience-based biases (Fang et al., 2015) and may be skeptical about new pesticides or green prevention and control technologies. This suggests that we should pay more attention to these two groups of people, strengthen guidance on the use of pesticides for cotton farmers under 30 years old, and publicize endosulfan-related alternative pesticides, technical knowledge, and their promotion for cotton farmers over 60 years old. When the cotton planting area was 51–100 *mu*, 100–499 *mu*, or more than 500 *mu*, the participants' average scores in terms of endosulfan-related knowledge decreased successively. The average score of the group over 500 *mu* was 3.96 (total score of 6), and the average score of the group under 50 *mu* was 4.64. This may be because the larger the cotton planting area, the higher the requirements for using related pesticides and the more cautious the use of alternative products and technologies. We can increase participants' confidence in using new methods and technologies by increasing the publicity of endosulfan-related alternative technologies and the effects and benefits of green prevention and control in large cotton-planting populations or by conducting pilot practices. When the permanent resident population of the participants' families was 1–2 persons, their attitudes toward the phasing out of endosulfan and the application of alternative technologies were more positive. With an increase in the permanent resident population, the corresponding average score gradually decreased, similar to the difference in the knowledge of endosulfan. Along with different cotton planting years, participants showed different attitudes toward the phase-out of endosulfan and the application of alternative technologies, which was similar to endosulfan-related knowledge.

Endosulfan replacement practice significantly differed between the cotton-planted area and cotton-planted years ($p = 0.022$, $p = 0.000$). There was no significant relationship between educational level, age, and permanent resident population ($p = 0.241$, $p = 0.347$, $p = 0.107$). The average score of participants with a cotton planting area below 50 *mu* was 6.82; with an increase in the planting area, the average score decreased gradually, and the average score for 500 *mu* and above was 5.79. The participants with less cotton planting area were more supportive of banning endosulfan and were more willing to use biological pesticides for green prevention and control; as cotton planting area increased, participants' acceptance of endosulfan replacement decreased, and they were less likely to adopt green prevention and control technologies because the high cost of pest control required for a large planting area made growers more cautious about green prevention and control technologies. Yang et al. (2019) found that farmers actively adopt green prevention and control technologies only when the expected net income of green prevention and control technologies is greater than that of traditional chemical pesticide-based prevention and control technologies. Meanwhile, with the increase in cotton-planting years, the more experienced the participants were, the higher the average score on endosulfan replacement practice, and the more likely they were to recognize endosulfan replacement practice. From this, we can pay more attention to and support groups with shorter cotton-planting years, carry out and organize relevant training, increase their cotton-planting experience, and form a good green ecology and environment concept.

According to previous studies, education, training, and publicity can positively affect participants' KAP (Ahmad et al., 2019; Shekoohiyan et al., 2022). Some researchers have found in the investigations of farmers in the Xinjiang cotton-planting region and rural residents in Jilin

Province (Mayire et al., 2016; Mou, 2016) that receiving scientific fertilization technology training is one of the key factors for farmers to reduce fertilizer applications, and related research has also suggested that it is necessary not only to publicize the technologies and methods of safe use of pesticides but also to hold regular training on pesticide technologies and methods to improve the practice of rural residents in using pesticides. Both reflect the importance of publicity and training for understanding and applying pesticides, fertilizers, and other related knowledge. Simultaneously, studies have found that environmental regulation (command-and-control type, publicity-and-education type, and economic incentive type) has a certain influence on cotton farmers' willingness and practice of environmental protection (Zhou et al., 2021). Among them, the command-and-control type can impose constraints on environmental protection practices but has no significant effect on cotton farmers' willingness; the publicity-and-education type can make cotton farmers realize the importance of environmental protection to accept and act for environmental protection in essence; however, the economic incentive type has no effect on cotton farmers' environmental protection willingness and practice under the current situation of less attractive environmental protection subsidies. This highlights the importance of publicity and education on cotton farmers' understanding and practices. Based on the survey data of this research, it can be determined whether or not the relevant government departments have organized training on green prevention and control technologies and whether or not the relevant government departments have significant and differentiated influences on endosulfan-related knowledge, attitude toward the phase-out of endosulfan, application of alternative technologies, and endosulfan replacement practice (Table 5). Compared with the participants without relevant experience, those participants who knew that the government had organized training on green prevention and control technologies and had publicized green prevention and control technologies were more able to master endosulfan-related knowledge and more willing to support the phase-out of endosulfan, the application of relevant alternative technologies and the endosulfan replacement practice; the average score of the informed participants was much higher than that of the uninformed ones. The results showed that the training and publicity of green prevention and control technologies organized by the relevant government departments could not only improve cotton farmers' knowledge level but also allow them to master scientific pesticide use methods in time, pay more attention to environmental problems, improve their pesticide use practices, and compensate for some deficiencies caused by differences such as age, planting years, and education level. This is conducive to their correct use of pesticides or technologies for green prevention and control and can make their practices meet the requirements of policy and environmental protection. At the same time, these also suggest that training for farmers can be integrated throughout the entire production process. In the early stages of production, the use of multimedia such as pictures and videos can be employed to provide easily understandable explanations of pesticide-related knowledge, application principles, and dosages. During the production process, targeted guidance on pesticide application and production can be provided to different households and fields through regular expert consultations and other means. After the production process, timely production exchange training sessions can be held to guide farmers in reviewing and summarizing their production practices, thereby forming a virtuous cycle.

As shown in Table 6, based on the Pearson correlation coefficient, we explored the correlation between the

Table 5 T-test results of government departments' trainings and publicity on KAP

Category	Variable	Classification	Average value	Standard deviation	*P* value
Knowledge	Relevant government departments have organized trainings on green prevention and control technologies	Yes	4.31	1.761	0.000
		No	3.30	1.757	
	Relevant government departments have publicized green prevention and control technologies	Yes	4.20	1.801	0.025
		No	3.45	1.697	
Attitude	Relevant government departments have organized trainings on green prevention and control technologies	Yes	4.93	1.445	0.000
		No	2.68	1.964	
	Relevant government departments have publicized green prevention and control technologies	Yes	4.77	1.556	0.000
		No	2.36	2.104	
Practice	Relevant government departments have organized trainings on green prevention and control technologies	Yes	6.81	1.682	0.000
		No	4.61	2.379	
	Relevant government departments have publicized green prevention and control technologies	Yes	6.64	1.818	0.001
		No	4.27	2.375	

Table 6 Pearson correlation coefficient between knowledge, attitude and practice

Category	Knowledge	Attitude	Practice
Knowledge	1		
Attitude	$r = 0.368$ $p = 0.000$	1	
Practice	$r = 0.212$ $p = 0.000$	$r = 0.619$ $p = 0.000$	1

participants' KAP, and it was observed that there was a significant correlation among the three variables. The data show a significant positive correlation between knowledge and attitude (r = 0.368), a weak positive correlation between knowledge and replacement practice (r = 0.212), and a significant positive correlation between attitude and replacement practice (r = 0.619). This shows that endosulfan-related expertise has a positive influence on the attitude toward the endosulfan phase-out and the application of alternative technologies, and the more positive their attitude toward the endosulfan phase-out and the application of alternative technologies, the more they are likely to support the endosulfan replacement practice. According to the theory of KAP, these three variables are interrelated and influenced by one another; mastery of knowledge and correct attitude form the basis of normalizing practice, and our study also demonstrates these features, consistent with the KAP model.

4 Conclusions

We drew the following conclusions from our study on endosulfan residues and endosulfan replacement practices of cotton farmers in the north-west inland cotton region:

1) ES-sulfate was the main endosulfan residue in the soil in the study region, followed by β-ES and α-ES, with detection rates of 71.4%, 60.4%, and 49.5%, and average residual contents of 0.569, 0.139, and 0.060 μg/kg, respectively. Endosulfan residues pose relatively low ecological and environmental risks. Source apportionment showed that endosulfan residues in the study region mainly originated from historical agricultural production and use, and there was no new source of endosulfan input, indicating that the Stockholm Convention has been well implemented in China.

2) Cotton farmers' knowledge of endosulfan-related knowledge generally remains low, which is not conducive to forming a correct understanding of endosulfan and will negatively influence cotton farmers' attitudes and practices. It is recommended that in the process of phasing out POPs pesticides, publicity and training for farmers should be strengthened, mainly focusing on training the male groups, the people aged < 30 and > 60, the people with short cotton planting years, and large cotton growers. This can make them fully aware of the harmful effects of POPs pesticides and improve their participation in the phase-out of highly toxic pesticides. In addition, because pesticide sales personnel strongly influence farmers' pesticide use practices, we should strengthen training on the safe use of pesticides for sales personnel so that they can better introduce popular science concerning relevant knowledge and pesticide safety to farmers.

3) Green alternative technologies are often scientific, systematic, and complex, which increases the early capital and labor input costs of green alternative technologies and lowers the input-output ratio. Consequently, large cotton growers should be cautious when adopting alternative green technologies. In the process of promoting green prevention and control technologies, we should focus on the promotion and application of green prevention and control technologies for large growers, and relevant departments should set up incentive funds and increase financial support to solve the problem of large initial capital investments in technology. The agricultural technology department should compile an application guide for green prevention and control technologies for cotton diseases and insect pests in easy-to-understand language to help cotton farmers better apply green prevention and control technologies.

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