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Review

Factors influencing Chinese farmers' proper pesticide application in agricultural products – A review

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ABSTRACT

Pesticide residues in agricultural products are a persistent food safety issue in China. The current review aims to get a comprehensive understanding of factors influencing farmers' proper pesticide application in China. To achieve that, the study developed an analytical framework based on the principles of the Theory of Planned Behaviour (TPB) and the techno-managerial approach. Following the framework, the study conducted a semi-structured literature review and yielded multiple factors related to farmers (i.e. their characteristics and TPB elements), external circumstances (i.e. governmental supervision, the roles of suppliers and the support of extension services) and technological conditions (i.e. equipment and environmental conditions), which can influence pesticide application of farmers. To improve farmers' behaviour, a stepwise approach of interventions targeted to different actors was proposed. Future research on the effectiveness of the application of the stepwise interventions on pesticide use is suggested.

1. Introduction

Pesticides are widely used against pest in agricultural production (WHO, 2017). About 33% of worldwide agricultural products are saved because of pesticide use (W. Zhang, Jiang, & Ou, 2011). Pesticides residue is one of the main safety issues in food production; especially in fruits and vegetables that are vulnerable to pest attack (Dinham, 2003). According to published data, there are 2473 the food alert notifications in fruits and vegetables, which are concerned about pesticides residues between 2015 and 2020 in Europe (RASFF, 2020). Similar issues have been reported in developing countries where pesticide residues particularly exceeded the maximum level in fresh produce (Amoah, Drechsel, Abaidoo, & Ntow, 2006; Darko & Akoto, 2008). China, as one of the biggest producers and users of pesticide worldwide (Xu, Kuang, Pay, Dou, & de Snoo, 2008), encounters a similar problem. For instance, export rejections of agricultural products from Japan, Canada and other countries due to the high level of pesticide residues or the use of toxic pesticides have been reported (Jia & Jukes, 2013; Wen, Yang, Dong, Fan, & Wang, 2018). Although the Chinese government increased the control of pesticide residues in agricultural products (F. Jin, Wang, Shao, & Jin, 2010), illegal pesticides are still being used (J. Zhou & Jin, 2009), like toxic cowpeas in southern China (Huan, Xu, Luo, & Xie, 2016).

Several studies indicated that pesticide residues relate to the behaviour of farmers, specifically their pesticide application (Jallow, Awadh, Albaho, Devi, & Thomas, 2017; L.; Wu & Hou, 2012). According to the Theory of Planned Behaviour (TPB), Ajzen (1991) suggests that a person's intention to conduct behaviour is the outcome of attitudes toward the behaviour, subjective norms, and perceived behaviour control. One's intention to conduct a behaviour combined with the perception of behavioural control leads to the actual behaviour. This theory has been widely applied to predict and explain health-related behaviour (Lien, Lytle, & Komro, 2002; Mullan & Wong, 2009) and the behaviour in organic farming (Kaufmann, Stagl, & Franks, 2009; Läpple & Kelley, 2013). A few studies also applied the TPB to get insight into farmers' intention of pesticide use as a precursor of behaviour (J. Wang, Chu, Deng Yuan, Lam, & Tang, 2018; L. Wu & Hou, 2012).

Besides the farmer-related behavioural factors, other studies showed that external circumstances (such as political and economic issues) (Xu et al., 2008) and technological factors (such as agricultural environment and equipment conditions) (Abhilash & Singh, 2009) can affect pesticide application. The occurrence of pesticide residues is thus not only dependent on farmers' attitude, subjective norms and perceived

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behaviour control, but technological factors seem to play a role as well. Luning and Marcelis (2006, 2007) stressed that food safety and quality is affected by the food production system characteristics, as well as the people and their organisational and external environment. This so-called techno-managerial (T-M) concept advocates the need to concurrently analyse the technological and managerial factors to gain a more comprehensive insight in causes of poor food safety and quality (Luning & Marcelis, 2006, 2007).

This review aims to get a comprehensive understanding of factors influencing appropriate pesticide application of farmers in China. The principles of the TPB and the T-M approach were used to develop an analytical framework. The framework guided a semi-structured literature review to collect data from empirical studies about factors affecting the pesticide application of Chinese farmers.

2. Analytical framework and semi-structured literature review

The analytical framework, in Fig. 1, proposes that the behaviour of farmers in applying pesticides can be affected by their characteristics and inner drives (TPB elements), the technological circumstances in the field and the external support they attain. Furthermore, it depicts the four main steps in applying pesticides, including pesticide selection, preparation, time and frequency selection, and spraying (Institute of Food and Agricultural Sciences, 2017; Northern Territory Government, 2012).

The TPB describes that the actual behaviour of people is affected by their intention to behave in a certain way (Ajzen, 1991). Based on the theory, we assume that farmers' intention to properly apply pesticides is affected by their attitudes to the behaviour (de Bon et al., 2014; Jallow et al., 2017), the subjective norms (i.e. perceived social pressure from neighbouring people and the society) (R. Liu, Pieniak, & Verbeke, 2013; Yin, Wu, Du, & Chen, 2010) and their perceived behaviour control (i.e. access to or limitations of alternative pest control tactics) (Abtew et al., 2016; Schreinemachers et al., 2017; Vidogbéna et al., 2016). Studies also indicated that the characteristics of farmers, such as education level, experience and knowledge, can influence their pesticide application (Khan, Mahmood, & Damalas, 2015; Schreinemachers et al., 2017; Sharma, Peshin, Shankar, Kaul, & Sharma, 2015).

The principle of the T-M approach describes that food safety and quality problems are the joint outcomes of technological conditions and administrative (managerial) conditions (Luning & Marcelis, 2006, 2007). The latter ones can be internal or external conditions. In this study, the external circumstances that farmers face and can have an impact on their behaviour include the role of government (i.e. the set-up, enforcement and communication of laws and regulations) (Jia & Jukes, 2013; Panuwet et al., 2012; Y.; Wang, Wang, Huo, & Zhu, 2015), the role of suppliers (i.e. selling purposes and their competence) (Schreinemachers et al., 2017; Sharma et al., 2015) and the support of extension services (Abtew et al., 2016; Nanyunja et al., 2015; Vidogbéna et al., 2016). Besides, technological conditions may support or constraint farmers' pesticide application due to the equipment conditions (i.e. availability of advanced equipment and equipment maintenance) (Doruchowski et al., 2017; Lekei, Ngowi, & London, 2014) or environmental conditions like weather (Abhilash & Singh, 2009; Gomez-Zavaglia, Mejuto, & Simal-Gandara, 2020).

The analytical framework was the basis for the semi-structured literature review to explore the most frequently reported factors in studies about pesticide application in China. The review focused on articles about pesticide application in China, published in the period from 2009 until 2020. The initial search used keywords ["pesticide use" AND "China"] or ["pesticide application" AND "China"] targeted to title, abstract and keywords, within the Scopus database. By checking abstracts and reading full texts of articles, the search then included articles that addressed one or more topics of the current framework, yielded 45 articles. To extract information about which factors affected pesticide application in China and the mechanism of the effects, a critical appraisal criterion was developed, including identifying potential factors and illustrating mechanisms on how factors affecting farmers' behaviour. Table 1 presents an overview of the identified factors and how they can affect pesticide application as found in the current review.

3. Influence of farmers' characteristics and their inner drives

3.1. *Influence of farmers' characteristics on pesticide application*

3.1.1. *Experience and knowledge*

The review shows that a substantial number of articles demonstrated that lack of knowledge associated with improper pesticide application (Table 1). When the knowledge of pesticide residues increased, the probability of willing to reduce pesticide use increased as well (Liguo Zhang, Li, Yu, & Yao, 2018). Farmers with more knowledge of pesticides conducted better application to decrease pesticide residues (J. Wang,

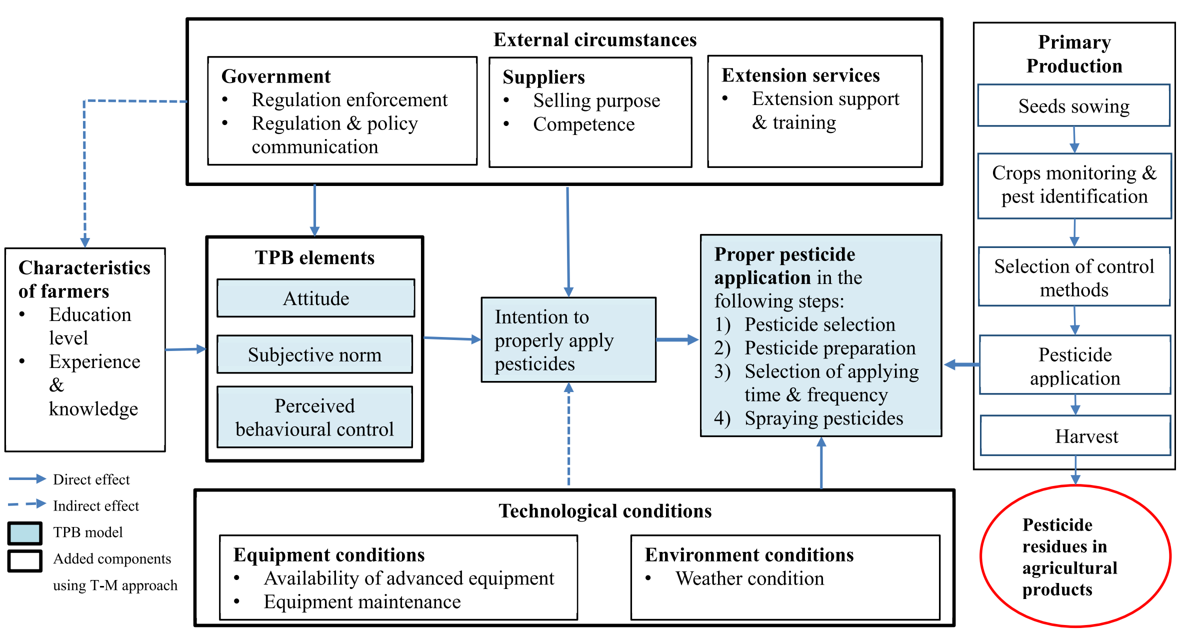

Fig. 1. The analytical framework of factors influencing farmers' pesticide application.

Table 1
Overview of factors, and how they can affect pesticide application as found in empirical studies in China.

Factors	Summarised information	References
Farmers' characteristics		
Experience & knowledge	• Lack of knowledge was associated with improper pesticide use. • Most of the Chinese farmers had inadequate knowledge about pesticides. • Farmers with more knowledge were more willing to reduce pesticides or conduct more practices to decrease pesticide residues. • The experience was positively linked to knowledge. • Experienced farmers usually had more knowledge about pesticide use, and thus were less likely to overuse.	(Chen, Huang, & Qiao, 2013; Fan et al., 2015; L. Hou, Huang, Wang, Hu, & Xue, 2012; Y. Huang et al., 2020; J. Jin et al., 2017; Nie et al., 2018; Jianhua Wang, Tao, et al., 2017; W. Wang, Jin, et al., 2017; X. Yang et al., 2014; C. Zhang et al., 2015; Liguo Zhang, Li, et al., 2018; L. Zhao et al., 2018; Q. Zhao, Pan, & Xia, 2020)
Education level	• Highly educated farmers were more likely to comply with proper pesticide use. • Poorly educated farmers had difficulties to understand and follow proper pesticide application. • Educated farmers were more willing to pay for pesticide reduction considering health risk. • Educated farmers were more willing to choose non-chemical pest control methods and adopt integrated pest management.	(Fan et al., 2015; B.; Hou & Wu, 2010; Huizhen Li, Eddy Y. Zeng, & Jing; You, 2014; Liu & Huang, 2013; W.; Wang, Jin, et al., 2018; Y.; Wang, Wang, & Zhu, 2018; Zhou et al., 2013)
TPB – attitude		
Concern on crop yield	• Farmers with loss aversion were more likely to overuse pesticides. • Many farmers believed that without or decreasing pesticide use would lead to yield reduction. • Farmers who were concerned about crop yield were less likely to reduce pesticide use or adopt non-chemical pest control measures. • Compared to other concerns (like product price or quality), farmers paid more attention to the quantity.	(Fan et al., 2015; Gong et al., 2016; D.; Li et al., 2012; Liu & Huang, 2013; Nie et al., 2018; Jianhua; Wang, Chu, Deng, Lam, & Tang, 2018; Y.; Wang, Jin, et al., 2018; L.; Zhao et al., 2018)
Concern on health risk	• Farmers were more likely to avoid excess pesticides when concerning health risk. • Farmers who had experience of pesticide poisoning used fewer pesticides. • Not many Chinese farmers were aware of pesticide's harm to health.	(J. Jin et al., 2017; Liu & Huang, 2013; Pan et al., 2020; W. Wang, Jin, et al., 2017; W. Wang, Jin, et al., 2018; Yu et al., 2017; L. Zhang, Li, et al., 2018; L. Zhao et al., 2018)
Concern on product quality	• Farmers concerned about product quality were more likely to comply with proper pesticide application. • Farmers who believed products of higher quality having higher values were more willing to comply with proper pesticide use to obtain higher profit.	(J. Wang, Jin, et al., 2017; L. Zhang & Li, 2016; L. Zhang, Li, et al., 2018; L. Zhao et al., 2018)
TPB – subjective norm		
Neighbouring people	• Farmers may have intent on reducing pesticide use if they perceive pressure from their families, friends and neighbours. • Farmers were more likely influenced by their families, especially when the agricultural products were produced for their own consumption. • Farmers' relationships with their social networks negatively correlated with pesticide overuse.	(Gong et al., 2016; J.; Jin et al., 2017; Jianhua Wang, May Chu, Yuan Yuan; Deng et al., 2018; W.; Wang, Jin, et al., 2018; L.; Zhang, Li, et al., 2018) (H. Li, E. Y. Zeng, & J You, 2014)
Social pressure	• Farmers who paid attention to the food safety issues were more likely to conduct proper pesticide application. • Farmers expected consumers with safety concern were more willing to pay a higher price for agricultural products of good quality and safety, thus reducing pesticide use for more profits. • Chinese traditional culture or moral standards encouraged farmers to regulate their behaviour of applying pesticides.	(Jianhua Wang, May Chu, Yuan Yuan Deng et al., 2018; L. Zhang, Li, et al., 2018; L. Zhao et al., 2018)
TPB – perceived behavioural control		
Personal ability	• Farmers' ability influenced their intention to conduct proper pesticide application. • Farmers who believed they could master a technology were more likely to adopt the technology. • Lacking ability restricted farmers from applying non-chemical pest control methods.	(Hu & Rahman, 2016; Jianhua Wang, May Chu, Yuan Yuan Deng et al., 2018; Zheng, Wang, & Wachenheim, 2018)
Limitation of alternative control methods	• The high cost of some non-chemical pest control tools or materials restricted farmers from applying them. • Extra labour or cost requirement also restricted farmers from adopting integrated pest management or physical pest control method.	(Hu & Rahman, 2016; Y.; Wang, Jin, et al., 2018; Zhou et al., 2013)
Governmental supervision		
Regulation enforcement	• The strength of regulation enforcement was positively associated with farmers' intention to comply with proper pesticide application. • Not many farmers were aware of the governmental supervision on the safety	(F. Jin et al., 2010; J. Jin et al., 2017; H. Li et al., 2014; Nie et al., 2018; Sun et al., 2020; Jianhua Wang, May Chu, Yuan Yuan Deng et al., 2018; J. Wang, Jin, et al., 2017; Wu et al., 2018; M. Yang et al., 2019; X. Yang et al., 2014; L.

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Table 1 (*continued*)

Factors	Summarised information	References
	and quality of agricultural products. • Regulation enforcement restricted pesticide suppliers from selling banned products. • Regulation enforcement was weak in some areas. • The Chinese government had implemented a lot of measures to improve pesticide control.	Zhang & Li, 2016; L. Zhang, Li, et al., 2018; M. Zhang et al., 2017; L. Zhao et al., 2018)
Regulation & policy communication	• Many farmers were unaware of pesticide residue testing by the government. • Farmers who had access to information about pesticide application would pay more attention to the consequence of pesticide use. • Some farmers did not trust the government.	(Fan et al., 2015; J.; Wang, Deng, & Diao, 2018; Y.; Wang, Jin, et al., 2018)
Suppliers		
Selling purpose	• Suppliers were one of the main sources of information for farmers. • Some suppliers deliberately amplified the recommended amount of pesticide use due to gaining profits or trust.	(S. Jin et al., 2015; H. Li et al., 2014; C. Zhang et al., 2015)
Competence	• Suppliers provided limited information about pesticide to farmers. • The knowledge level of pesticide suppliers varied largely. • Some suppliers provided useless pesticides to local farmers.	(Fan et al., 2015; S.; Jin et al., 2015; H.; Li et al., 2014; X.; Yang et al., 2014)
Extension services		
Access to support & training	• Limited access to support and training of extension services would restrict farmers from complying proper pesticide application. • Having access to support and training, farmers were more likely to know more information about the correct pesticide application. • The current agricultural extension services in China faced some problems, such as lacking support from government and busy with commercial activities rather than providing guidance on agricultural activities. • The participation rate was low although some extension services provided training.	(Fan et al., 2015; Hu & Rahman, 2016; J. Huang et al., 2018; S. Jin et al., 2015; Liu & Huang, 2013; Jianhua Wang, May Chu, Yuan Yuan Deng et al., 2018; Jianhua Wang, Chu, & Ma, 2018; J. Wang, Jin, et al., 2018; C. Zhang et al., 2015; L. Zhang, Li, et al., 2018; Zhai et al., 2018)
Equipment conditions		
Availability of advanced equipment	• No articles directly discussed whether the availability of advanced equipment would affect farmers' pesticide application. • Some articles compared the spraying effects of different pesticide spraying equipment. • Advanced equipment like UAV was rarely adopted due to high cost and technical limitations.	(Guo et al., 2018; X He, 2018; X. He et al., 2017; Y. Li et al., 2018; G. Wang et al., 2019; J. Zhang et al., 2019; H. Zhao et al., 2014; Zhai et al., 2018)
Environmental conditions		
Weather conditions	• Increased precipitations and/or temperature would enhance pesticide use. • The effect of the weather was stronger in southern China compared to the northern. • Increased precipitations and temperature enhanced the frequency and severity of pest attack and enhanced pesticide loss.	(H. Li et al., 2014; Y. W. Zhang, McCarl, et al., 2018)

Tao, Yang, Chu, & Lam, 2017). However, many Chinese farmers have inadequate knowledge regarding the production requirements (Nie, Heerink, Tu, & Jin, 2018), the relationship between pesticides and agricultural products (L. Zhang, Li, et al., 2018), prohibited pesticides, and harmful effects of pesticide residues (L. Zhao, Wang, Gu, & Yue, 2018), as well as information acquisition ability (Q. Zhao, Pan, & Xia, 2020). Zhao and co-researchers (2018) found, in a study about vegetable farmers from Jiangsu, Anhui and Shandong provinces, that 40% of the respondents did not know any forbidden pesticides, and only half of the respondents were able to name one or a few banned pesticides. Also, in their previous two-year farming, 85% of farmers had used pesticide 666, which is banned in China since the 1980s (L. Zhao et al., 2018). Above findings were consistent with previous studies in other countries. Farmers from other emerging countries, also showed low performance in pesticide knowledge (Schreinemachers et al., 2017; Stadlinger, Mmochi, Dobo, Gyllbäck, & Kumblad, 2011). Besides, the influence of farmers' production experience on pesticide use cannot be ignored (Y. Huang, Luo, Tang, & Yu, 2020). Khan and Damalas (2015) found through a survey that more than 90% of the sampled farmers learned agricultural techniques through their own exploration or by following their parents' experience. In China, experienced farmers usually had more knowledge about pesticide application and were less likely to overuse (J. Wang, et al., 2018; J. Wang, Jin, He, & Gong, 2017). In contrast, another study found that years of farming had a negative effect. They explained that older farmers with more experience were mostly low-educated. They perceived less risk and more benefits from using pesticides (J. Jin, Wang, He, & Gong, 2017).

3.1.2. Education level

Table 1 also depicts that multiple articles emphasized that higher educated farmers were more likely to comply with proper pesticide application. For example, a survey demonstrated that higher educated farmers were more willing to pay for health risk reduction of pesticide use, as they had a better understanding of the consequences of pesticide use and the need to decrease health risk (W. Wang, Jin, et al., 2018). Wang, Wang, and Zhu (2018) estimated that increasing education level, the probability of choosing non-chemical pest control methods increased, thus leading to using fewer pesticides. Previous studies in other countries also confirmed that education level positively related to proper compliance to pesticide application (Lekei et al., 2014; Sharma et al., 2015). The reasons were that lower educated farmers usually had difficulties to read labels (Lekei et al., 2014; Sharma et al., 2015) or to understand the negative effects of pesticides (Lekei et al., 2014).

3.2. Influence of farmers' drives on their intention to apply pesticide properly

The inner drives of one's behavioural intention, which is in the current study applying pesticides properly (Fig. 1), are comprised of attitude, subjective norm and perceived behaviour control as defined in the Theory of Planned Behaviour (Ajzen, 1991).

3.2.1. Attitude towards pesticide application

Multiple articles established that attitude has a strong influence on farmers' intention to comply with proper pesticide application (Table 1). Several studies showed that many Chinese farmers believed that without or decreasing pesticide use would lead to crop yield reduction (Nie et al., 2018; J.; Wang, Jin, et al., 2018; Y.; Wang et al., 2015). For instance, more than 90% of respondents believed that choosing non-chemical pest control measures would significantly decline their production (Y. Wang et al., 2015). Compared to other factors like product price or quality, farmers were more concerned with the quantity (L. Zhao et al., 2018). Especially for poorer farmers, the production was the most important food supply for their families (Gong, Baylis, Kozak, & Bull, 2016). Likewise, a majority of farmers from other developing countries considered pesticides as indispensable for high yields (Ríos-González, Jansen, & Javier Sánchez-Pérez, 2013) (Abtew et al., 2016; Jallow et al., 2017; Schreinemachers et al., 2017) (Nguetti, 2018). Particularly, this believing was commonly found in farmers who persuaded higher returns in the short term (E. M. Liu & Huang, 2013).

Following crop yield concern, some articles showed that farmers' concern about health risk was also likely to restrict them from using excess pesticides (Table 1), especially for those who had an experience of pesticide poisoning (E. M. Liu & Huang, 2013), or those who produced food for family consumption (L. Zhang, Li, et al., 2018), or those who perceive the risk to food quality and human health (Pan, He, & Kong, 2020; W.; Wang, Jin, et al., 2017). However, researches still found that few Chinese farmers fully understood the harmfulness of pesticide residues to human health (L. Zhang, Li, et al., 2018). This could also explained the abuse of banned and restricted pesticide residues observed in prior study (Yu et al., 2017). On the contrary, studies in southeast Asia, Ecuador, and Peru reported that although farmers understood the health risk of pesticide, they still relied heavily on it (Orozco et al., 2009; Schreinemachers et al., 2017).

Only a few studies indicated the positive effect of quality concern on complying proper pesticide application, for example, farmers were more willing to adopt eco-friendly agricultural production (L. Zhang, Li, et al., 2018). It is worth noting that when farmers believed that higher product quality would increase the price and obtain more benefit, they were also more willing to ensure product quality (L. Zhang, Li, et al., 2018).

3.2.2. Subjective norm from neighbouring people and society

As shown in Table 1, some articles suggested that Chinese farmers intended to reduce pesticide use if perceiving pressure from their neighbouring people, like families, friends and neighbours (J. Wang, Jin, et al., 2018). Farmers were more likely influenced by their families, especially when the agricultural products were produced for own consumption (Gong et al., 2016). Previous research performed in Mexico, India and Tanzania suggested that neighbouring farmers can share erroneous experience and information due to lacking knowledge. That may encourage the arbitrary use of pesticides (Ríos-González et al., 2013; Stadlinger et al., 2011). In China, farmers trust their networks and their relationships, which also affected their pesticide application (J. Jin et al., 2017). For example, farmers with a higher level of social trust were more willing to reduce pesticide use as they expected other farmers in the community followed the action to protect the common good (W. Wang, Jin, et al., 2018). Besides, a few studies (Table 1) showed that social pressure encouraged Chinese farmers to comply with proper pesticide application (J. Wang, Jin, et al., 2018; L. Zhang & Li, 2016; L. Zhao et al., 2018). Pressures from society include concerns about the safety of agricultural products and the traditional culture of moral requirement. Farmers expected consumers with safety concern were more willing to pay a higher price for agricultural products of good quality and safety, thus they would like to reduce pesticide use for gaining more profits (L. Zhao et al., 2018). Nowadays, Chinese consumers increasingly demand safe products and tend to purchase organic and green foods (R. Liu et al., 2013; Yin et al., 2010). Regarding moral concerns, an article demonstrated the importance of Chinese traditional culture, in encouraging farmers to regulate their behaviour. If farmers valued traditional culture or moral standards, the probability of non-compliance would reduce 17% (L. Zhang, Li, et al., 2018).

3.2.3. Perceived behaviour control

A few articles demonstrated that Chinese farmers perceived themselves having a low ability to comply with standard pesticide application (Table 1). The ability was mainly measured through checking if farmers had knowledge and skills to regulate pesticide application (J. Wang, Jin, et al., 2018), the confidence of using advanced technology (Zheng, Wang, & Wachenheim Cheryl, 2019), or difficulties to conduct intercropping when lacking labour (Hu & Rahman, 2016). The way of measurement was consistent with other TPB research in which the higher the personal ability, the higher intention to conduct a behaviour (Bai, Tang, Yang, & Gong, 2014, Kaufmann et al., 2009). Moreover, a few studies also mentioned that Chinese farmers perceived the limitation of alternative control methods (Table 1). Non-chemical pest management, like using paper-bag traps and sticky-paper traps, was effective to control pest, but these methods relatively cost a lot. Thus, farmers were unwilling to use them (Y. Wang et al., 2015). Besides, extra labour or cost requirement restricted farmers from adopting integrated pest management or physical pest control method (e.g. intercropping) (Hu & Rahman, 2016; K.; Zhou, Ma, & Jia, 2013).

4. The role of external circumstances in pesticide application

4.1. Governmental supervision

A substantial number of articles pointed out the importance of governmental supervision (Table 1). For instance, when the regulation was effectively enforced, farmers were more likely to aware of the requirement of limiting pesticide use (J. Wang, Jin, et al., 2018; M. Yang, Zhao, & Meng, 2019). The stricter the regulation enforcement, the stronger the farmers' willingness to reduce pesticide use (L. Zhang & Li, 2016; L. Zhao et al., 2018). Also, systematic enforcement of the regulations restricted pesticide suppliers from selling banned products (X. Yang et al., 2014). The Chinese government has been taking measures in the last 30 years to improve pesticide control and ensure the food safety of agricultural products, such as the enactment of laws, regulation and agricultural standards (i.e. maximum residue limits), and the upgrade of inspection system (i.e. added laboratories and better analytical methods (F. Jin et al., 2010). Nowadays, the public can also check the report of a regular inspection on the official websites of government (Agriculture, 2017). However, effective regulation enforcement in China is still in development (Li, Zeng, & You, 2014; Sun, Zhang, & Hu, 2020; Y.; Wang et al., 2015; M.; Zhang, Jin, Qiao, & Zheng, 2017; K.; Zhou et al., 2013). For example, some certified-food (i.e. Green Foods or Organic) farmers did not comply with production requirements, and an organic certificate could even be purchased with a cheap price in villages where governmental control was not yet strict (Nie et al., 2018). Similarly in Ecuador and Thailand, lack of effective regulation enforcement affected the flooding of illegal pesticides, and the misuse or overuse of pesticides (Panuwet et al., 2012). Remedies such as easing farmer's access to modern technologies and knowledge, and improving environmental regulation and enforcement will help to solve pesticides overuse/abuse problems (Y. Wu et al., 2018).

Regulation and policy communication are also important for farmers to obtain appropriate information. Farmers having more access to adequate information on the pesticide application seem to pay more attention to the consequence of pesticide use (Wang J, 2018). However, a survey found that more than 90% of the participating farmers believed there were no residue tests by the government, which suggested an ineffective communication from government to farmers. Nevertheless, although some farmers knew that the government was promoting non-chemical pest management methods, this did not affect their pesticide application (Y. Wang et al., 2015). Another study revealed that even though the government put efforts in promoting the adverse effects of pesticides in northern China, most farmers there do not trust the authorities and believe that the government overstated the hazards of pesticides (Fan et al., 2015).

4.2. Effects of pesticide suppliers

The review showed that there are two main effects of suppliers on Chinese farmers' pesticide application (Table 1). Firstly, suppliers' selling purpose was quite important as many farmers obtained information from pesticide suppliers about the pesticides to buy and the dosage of use (S. Jin, Bluemling, & Mol, 2015; C. Zhang et al., 2015). Studies showed that some suppliers deliberately amplified the recommended amount of pesticide use due to different selling purposes, like maintaining trust (S. Jin et al., 2015; C. Zhang et al., 2015). For instance, to maintain their relationship and reputation, many township or village suppliers recommended local farmers using more pesticides to ensure pest control effects. Additionally, they usually did not dare to sell fake pesticides to avoid losing reputation among the community (S. Jin et al., 2015). This result was a bit different from the situation in India and southeast Asia where suppliers usually amplified dosage due to gaining more profits (Schreinemachers et al., 2017; Shetty, Murugan, Hiremath, & Sreeja, 2010).

Secondly, many Chinese suppliers offered little information about the safe and proper application of pesticides (Fan et al., 2015; S.; Jin et al., 2015). This finding was consistent with previous literature that found suppliers seldom provide comprehensive information to farmers in Ecuador and Peru (Orozco, Cole, Forbes, Kroschel, Wanigaratne, & Aric 2009). Additionally, the knowledge level of Chinese suppliers varied substantially due to differences in access to information (Fan et al., 2015; S.; Jin et al., 2015). For instance, upstream suppliers usually had better access to information and technical training courses compared to downstream suppliers (S. Jin et al., 2015). However, having more close contact with local farmers, many downstream suppliers had little knowledge of pesticides and they were likely to provide wrong pesticides to farmers (Li et al., 2014). Similarly in Kenya, pesticide suppliers had inadequate training and transferred erroneous information to farmers (Nguetti, 2018). In contrast, only one study performed at Wei River catchment in China found that most of the pesticide suppliers were well-known of pesticide application knowledge, such as protective measures, storage conditions, and container deposal (X. Yang et al., 2014).

4.3. The supportive role of extension services

A substantial number of articles also pointed out that limited access to support and training of extension services would restrict farmers from complying proper pesticide application (Table 1). Studies performed in other countries also suggested that providing external support and training to farmers about pesticide application is associated with a reduction in pesticide overuse (Jallow et al., 2017; Khan et al., 2015; Sharma et al., 2015), as farmers are more likely to have more knowledge, more positive attitude to adopt new technology or alternative pest control methods (Timprasert, Datta, & Ranamukhaarachchi, 2014) (Vidogbéna et al., 2016). However, the current situation of agricultural extension services (AES) in China faced some problems, such as weak governmental support (Hu & Rahman, 2016), active in commercial activities rather than guiding agricultural activities (C. Zhang et al., 2015), and low participation rate of training (S. Jin et al., 2015; E. M. Liu & Huang, 2013). These are priorities towards achieving a more ecologically-based approach on smallholder farms (J. Huang et al., 2018).

5. Technological circumstances affecting pesticide application

Although the current analytical framework (Fig. 1) proposed the effects of the technological condition in farmers' pesticide application, only a few articles (Table 1) discussed technological condition as a factor that could play a role.

5.1. The role of equipment conditions

Prior study has revealed agricultural mechanization services used by farming households significantly increase farm yields (Benin, 2015). Farm machine use can help improve pesticide spraying efficiency, which induces smallholder farmers to spray less (J Zhang et al., 2019). What's more, using equipment as insect-trapping lamp can reduce pesticides without any adverse effect on crop yields (Guo et al., 2018). However, advanced equipment, like UAV, was not widely commercialised and promoted (Fu, 2009), due to its high cost and multiple technical limitations (X He, 2018; X. He, Bonds, Herbst, & Langenakens, 2017). Regarding regular equipment maintenance, study from other emerging countries pointed out that equipment maintenance was associated with proper pesticide application (Puckett, 2018). Many farmers from developing countries did not properly maintain their pesticide spraying equipment (i.e. not calibrating, leaving pesticides in the tank overnight or arbitrarily damaging equipment), leading to damaged or blocked equipment, excess or insufficient pesticides used, and mixing different pesticides in the equipment (de Bon et al., 2014; Lekei et al., 2014).

5.2. The relation between weather conditions and pesticide use

A few articles supported the role of weather condition in enhancing pesticide use (Table 1). Especially in southern China, the climate effect was more influential compared to that in northern China (de Bon et al., 2014; Lekei et al., 2014). The reason is that increased precipitations and temperature usually enhance the frequency and severity of pest attack. Southern China is much warmer than northern regions, thus the effect of increased climate change is stronger (Y. W. Zhang, McCarl, et al., 2018). This result was in alignment with studies that analysed the situation in America and Malaysia, where higher temperature and more rainfall increased pesticide use as the pest attack was more severe (Koleva, 2009). Previous studies also pointed out that weather condition can influence farmers' decision on pesticide application, such as spraying time and frequency (Ubeda, Hornedo-Ortega, Cerezo, Garcia-Parrilla, & Troncoso, 2020; Zhai, Song, Qin, Ye, & Leipnik, 2018).

6. Stepwise interventions for improvement of pesticide application

The current review revealed that farmers pesticide application was the outcome of multiple factors and these factors rooted at different actors, such as farmers (i.e. their knowledge, attitude and subjective norm), suppliers (i.e. their selling purposes and competence), extension services (i.e. support and training) and government (i.e. regulation communication and enforcement). To promote appropriate pesticide application and even reducing pesticide use, multiple interventions targeted at different actors should be taken.

Fig. 2 proposes a stepwise approach of interventions, ranging from the elementary, to the intermediate, and advanced stage as previously described by (Macheka, Spelt, Bakker, van der Vorst, & Luning, 2018). The idea behind the proposed stepwise interventions is that farmers cannot change all the circumstances that affect their, in this case, pesticide application behaviour, at the same time. It requires, for

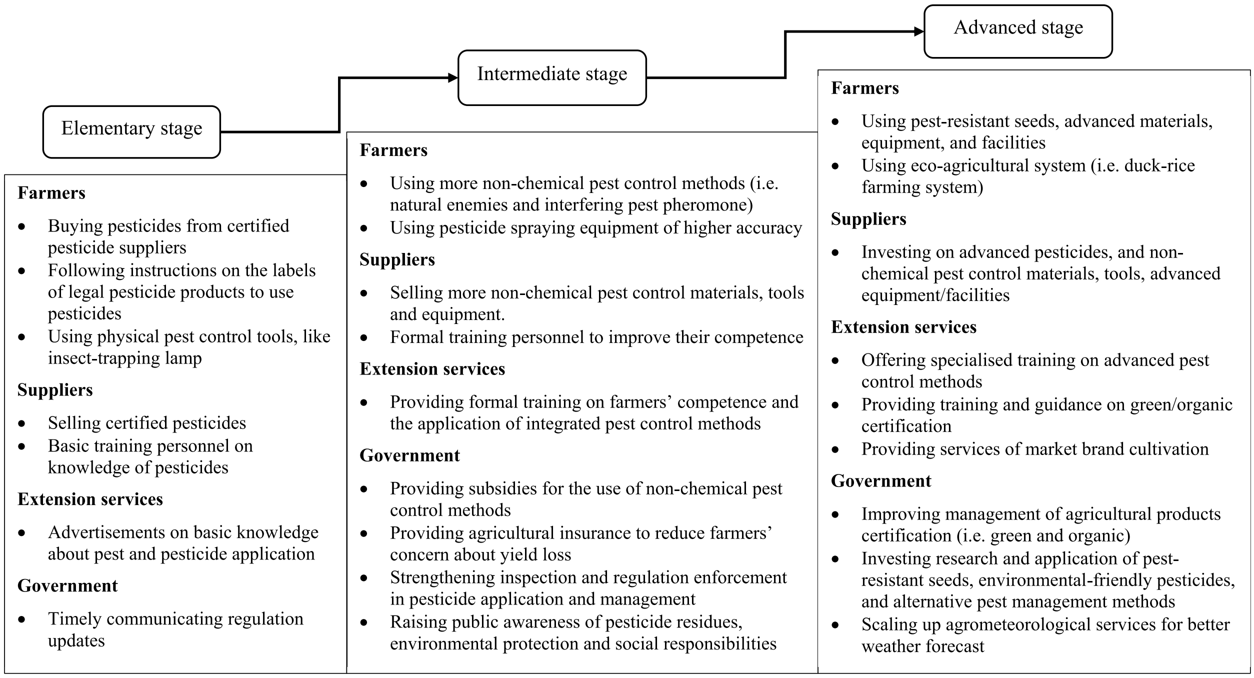

Fig. 2. Stepwise interventions at different development stages in mitigating pesticide residues.

example, investments in training, changing habits, investing in equipment, etc, which can be costly and time consuming. A stepwise approach may help to achieve the final goal through smaller efforts, which are more feasible. Therefore, the development stages differ from each other in intensity of capacity building required, investment needed, and time span to implement the intervention based on (Macheka et al., 2018). The proposed interventions for each stage are further differentiated based on the actors involved in the system, which are the farmers, suppliers, extension services, and government. Each contributes differently to the problem of high pesticide levels, and each can implement different interventions to mitigate the problem.

The common features of interventions in the elementary stage include being simple, low-cost, and easy to apply in the short term. For farmers, the elementary interventions could include buying pesticides from certified suppliers, following proper instructions and using physical pest control tools (Guo et al., 2018; Macheka et al., 2018; Nie et al., 2018). Suppliers could sell certified pesticides and provide basic training to their personnel (S. Jin et al., 2015; Li et al., 2014). Extension services could provide basic training about pesticide application to the farmers, whereas the government could timely communicate regulation updates to farmers by local officials (S. Jin et al., 2015).

At the intermediate stage, the common features of interventions include requiring a certain knowledge level (less simple), requiring small investments, and more time consuming. Farmers could start to use non-chemical pest control methods to reduce pesticide use, which requires more knowledge, and invest in better pesticide sprayers (J. Huang et al., 2018; Y. Wang, Wang, & Zhu, 2018). Similarly, suppliers could provide appropriated pest control products to farmers and train their personnel in use of non-chemical products (S. Jin et al., 2015; Y. Wang, Jin, et al., 2018). For extension services, formal training on integrated pest management to improve farmers' competence have been suggested (J. Wang, Jin, et al., 2018). Furthermore, the government could provide subsidies and agricultural insurances, strengthening inspection and regulation enforcement, and raising public awareness on agricultural pesticides (J. Wang, Jin, et al., 2018; Y. Wang, Jin, et al., 2018).

Lastly, interventions at the advanced stage are characterised by a high level of knowledge required, substantial investment and long-term system improvements. For farmers, they could use pest-resistant seeds, advanced equipment, and upgrade to eco-agricultural systems to substantially reduce pesticide use (J. Huang et al., 2018; Jiaen Zhang, Zhao, Chen, & Luo, 2009). Suppliers could invest in improving the effectiveness of pesticides and develop specific pest control equipment to improve the accuracy of pesticides dosing (Jing Zhang et al., 2019). Extension services could provide specialised training on using advanced equipment and facilities, developing towards green and organic certification, and even market brand cultivation (J. Wang et al., 2018, Zhao, Wang, et al., 2018). Additionally, long-term interventions for the government could include certification management, pesticide-related research and agrometeorological services as suggested by various researches (Nie et al., 2018; Zhang, McCarl, et al., 2018, Wang, Wang, et al., 2018).

7. Conclusions and recommendations

An analytical framework developed based on the principles of the Theory of Planned Behaviour and the techno-managerial approach was used to conduct a semi-structured literature review about factors affecting the pesticide application of Chinese farmers. The review yielded a multitude of factors related to farmers (i.e. their characteristics and TPB elements), external circumstances (i.e. governmental supervision, the roles of suppliers and the support of extension services) and technological conditions (i.e. equipment and environmental conditions), which influence farmers to apply pesticides properly. To improve farmers' behaviour and eventually mitigate pesticide residues, it is proposed to follow a stepwise intervention approach targeted to the different actors (i.e. farmers, suppliers, extension services and government) involved in the complex situation of pesticide application. Therefore, future research on the application of stepwise interventions is suggested.

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