Since January 2020 Elsevier has created a COVID-19 resource centre with free information in English and Mandarin on the novel coronavirus COVID-19. The COVID-19 resource centre is hosted on Elsevier Connect, the company's public news and information website.

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Farmers' cognition of the COVID-19 outbreak, risk perception and willingness of green production

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ABSTRACT

Existing literature reports that COVID-19 outbreak may affect people's risk perceptions, with disturbances ranging from mild negative emotional reactions to overall mental health. At the same time, the pneumonia pandemic reveals all the vulnerabilities and weaknesses of our ecosystem and makes people reflect on traditional ecologically harmful production practices. Therefore, the aim of this paper is to review the existing scientific literature on these variables, through a survey and empirical analysis, in order to present and comment on the effects and mechanisms of influence between them. The results showed that: (1) Increasing farmers'cognition of COVID-19 outbreak could significantly enhance the green production willingness. Specifically, the probability of "Very willing"to participate in green production increased by 29.9% for each unit of increase in cognition. (2) Farmers'cognition of COVID-19 outbreak can significantly enhance the level of risk perception and thus enhance their green production willingness, that is, risk perception is an important transmission medium of this effect. (3) The analysis of inter-generational difference showed that the impact of cognition of COVID-19 outbreak on green production willingness was significant for both the new generation and the old generation. On the basis of this, some policy suggestions are put forward, such as strengthening the propaganda and education of natural ecological environment protection, establishing the propaganda mechanism of green agricultural products market in the later period of epidemic situation, raising farmers'risk perception level through multi-channels and so on.

1. Introduction

It has become a common understanding that the COVID-19 has a wide spread route, a strong infectivity, a long incubation period, a fast spreading speed and a great difficulty in prevention and control, the resulting epidemic spread rapidly across the globe (Hsiang et al., 2020). It has become the most concerned public health event in the world (Ozamiz-Etxebarria et al., 2020). According to the latest real-time statistics of the WHO, as of July 2, 2022, there were 54,5226,5,550 confirmed cases and 6,334,728 deaths worldwide. No one could have failed to notice the fact that the COVID-19 outbreak has had a huge impact on many industries and fields, including agriculture (Wang et al., 2020), consumer economy (Mehrolia et al., 2021), ecological environment (Crossley, 2020), and public psychology (Cerami et al., 2020). In particular, the epidemic has brought about profound changes in agricultural production and farmers' lives, with Covid-19 having a significant impact on agricultural profitability, resulting in higher production costs and lower profitability for farmers. It has also led to an inadequate supply of agricultural production materials, which has an impact on farmers' production intentions and livelihood decisions (Zhuo et al., 2020). Interestingly, organic green agriculture is highly resistant to the impact of the covid-19 pandemic, and organic green-producing farms show a high degree of resilience (Grigorescu et al., 2022). Meanwhile, one thing is certain: COVID-19 has attracted worldwide attention to the connection between environmental and health issues, COVID-19 may have implications for green production in humans (Armstrong et al., 2020). The epidemic could affect the likelihood and intensity of farmers' adoption of sustainable agricultural practices (SAP) (Martey et al., 2022). On the one hand, the COVID-19 outbreak has had a profound impact on mass food consumption (Foddai et al., 2020), and due to the high contagiousness and uncertainty of the virus, major epidemic events will often have an impact on the willingness to consume

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agricultural products, and people are increasingly concerned about food safety (Wang et al., 2021). 'Consumers' demand for safe, ecological and healthy agricultural products has increased (Mattioli et al., 2020; Brenna et al., 2021; Rana and Paul, 2017). Therefore, producers prefer toproduce healthful products to meet consumer preferences in a fluctuating market in order to gain greater profits (Ouyang and Fu, 2020; Dixit and Stig litz, 1977). On the other hand, the latest research proves that environmental issues have a significant impact on the spread of COVID-19 and associated mortality (Shakil et al., 2020; Muhammad et al., 2020). With global climate change and ecosystem imbalances, wildlife is coming into closer contact with humans and animal pathogens can be transmitted to human populations. (Roche et al., 2020). Consequently, more and more people reflect on the lack of reverence for nature and the environment in the past (Marazziti et al., 2021; Ben Hassen et al., 2020), and strengthen the value of harmonious coexistence between man and nature. In other words, the human cognition of COVID-19 promotes a green, safe and healthy life philosophy, and the pursuit of goals to produce and operate in a more environmentally and ecologically sound manner in order to prevent further and more frightening pandemics in the future (Hall et al., 2020).

The above-mentioned literature expounds that Covid-19 has attracted the attention and attention of mankind to the environmental problems and the sustainable development of agriculture. In addition, some studies have expounded that Covid-19 has positive significance to the green production behavior of farmers. Martey et al. (2022) argue that farmers' perceptions of COVID-19 shocks affect their likelihood and intensity of adopting structural sustainable action programmes in agricultural production measures. Teng et al. (2022) found that individual characteristics, government guidance, industrial organization and market regulation had positive effects on green production behavior of farmers in COVID-19 period. However, no further conclusions have been drawn with regard to the direct impact of COVID-19 on farmers' behavior. More importantly, a serious problem is being overlooked. It is not the disease itself that causes farmers to be willing to go green and protect the environment, but the farmers' cognition of Covid-19 changed their deep-seated judgment and cognition, and finally made the corresponding production behavior choice. From this point of view, the above-mentioned literature did not explore the impact of COVID-19 on the green production behavior of farmers, so this study attempts to propose a new research framework, further identify the key mediation variables.

After the COVID-19 outbreak, governments around the world adopted some epidemic prevention measures quickly, which effectively alleviated the epidemic of new coronary pneumonia (Lin et al., 2020). Governments' responses to the outbreak have varied, with Europe and the United States focusing on self-immunity and China imposing regional urban blockades, all limiting access and social distance ' (Haleem et al., 2020). These social controls have had a huge negative impact on the psyche of everyone, changing people's social activities and behavior and exacerbating public fears of COVID-19 outbreak'' (Betsch et al., 2020). Clearly, the impact of COVID-19 on an individual's psychology and behavior is an important research topic, so we sought to incorporate people's perception of risk with COVID-19 into the research framework for design and validation. Numerous studies have shown that COVID-19 might have an impact on human psychological health (Cerami et al., 2020), public emotional reactions (Qian and Li, 2020), health risk ideas (Jian et al., 2020), and psychological interventions (Duan et al., 2020). Many previous studies have confirmed a positive correlation between people' s risk perception for certain types of things and their awareness and actions to protect the environment (Steg and Sievers, 2000; Zhang et al., 2014; Bockarjova and Steg, 2014). For now, the COVID-19 outbreak has had varying degree of psychological impact on groups such as the elderly, farmers, infected patients, suspected patients, medical workers, volunteer workers and other groups (Kang et al., 2020; Wang et al., 2020; Hou et al., 2021). Substantial number of respondents stated the COVID-19 outbreak had a serious psychological impact and felt afraid and worried about the outbreak (Cerami et al., 2020), and increase anxiety about the epidemic (Wang et al., 2020). Risk perception of COVID-19 was thus proposed, initially to explain the impact of viruses on people taking preventive public health measures (Dryhurst et al., 2020). The more people know about COVID-19, the more they perceive the risk of viral infection and change social behavior (Reznik et al., 2021), as well as examine COVID-19′ s effect on people' s concerns about the state of the environment (Gong and Sun, 2020). Many results confirm that perceived risk to COVID-19 is significantly associated with the likelihood of taking protective and preventive measures such as self-isolation and wearing a mask; this confirms the role of risk perception in influencing people's behavior (O' Connor and Assaker, 2021). Therefore, we try to use risk perception as a mediator variable to explore the effect of people's views of COVID-19 on their willingness to produce.''

Existing research on risk perception provides useful lessons that can help to understand. However, despite the severe lockdown restrictions imposed by the COVID-19 outbreak, people's social activities and behavior are changing, the risk perception of COVID-19 in the existing study mainly included the perception of the health risk of COVID-19 or the people around it but not the multi-dimensional attributes of the accident itself, which is not scientific and circular enough. This study attempts to provide a more comprehensive and accurate interpretation of risk perception on this basis, borrowing from the theoretical definition of unexpected events, through the duration of the epidemic, the risk perception of COVID-19 was measured from three aspects of propagation space and intensity. And there are few studies to verify the impact of risk perception of COVID-19 on farmers' micro-level green production willingness through investigation and empirical analysis. In the context of agricultural production, producers enjoy the natural ecological environment together with their acquaintances, and the whole earth and human beings as a whole (O' Connor and Assaker, 2021). As risk perception increases, farmers are more likely to worry about environmental problems that could exacerbate future epidemics, they are more willing to invest in health and make environmentally friendly choices in production to prevent environmental damage caused by the exacerbation of the epidemic. Especially in China, the greater lack of medical supplies, stricter prevention and control measures, and inconvenience in purchasing supplies may lead to a potentially greater panic among farmers compared to urban residents. Causing its higher risk perception, and will increase the health investment to improve the ability to resist risk (Wang et al., 2021; O' Connor and Assaker, 2021). For farmers, the lack of medical care, health care and health care facilities, the most convenient and low-cost health investment method is green production, which can not only increase the consumption of healthy food and nutrition intake to improve the body immunity, but also reduce the reduction of chemical residues in soil pesticides and fertilizers, resulting in the reduction of the body's immune damage (Luo et al., 2022a,b).

As a major public health emergency attracting global attention (Fitzpatrick et al., 2020), COVID-19 outbreak has already lasted for more than two years and is still spreading worldwide (Ghebreyesus, 2020). Until now, no government has publicly announced that he has completely got rid of the negative impacts of COVID-19. People are still living with COVID-19, and it will take more time for the world to overcome all the follow-up impact caused by the epidemic (Marroquín et al., 2020). The economic recovery during the epidemic comes at a critical period for ecological and sustainable development (Rosenbloom and Markard, 2020). The world has recognized this and strongly calls on governments to support low-pollution, healthier and cleaner recovery plans in the post-epidemic economic recovery phase, taking into account sustainable ecological development (Gawel and Lehmann, 2020; Hepburn et al., 2020). It has become a general consensus of the international community to accelerate the "green recovery and low-carbon transformation" in the later stage of the epidemic (Climate Action Tracker, 2020; Allan et al., 2020), and green development will become the leading direction of post-epidemic economic development (IEA, 2020;

Lenzen et al., 2020; Gillingham et al., 2020). As one of the regions most severely affected by the COVID-19 epidemic, the green development of agriculture should be the focus of ecological sustainable development in China at a later stage. . However, little is known about how the COVID-19 pandemic affects changes in psychological responses and behavioral intentions, such as allowing farmers to choose eco-friendly mode of production. Therefore, it is crucial to investigate the relationship between COVID-19 perceptions and farmers' willingness to produce green and its influence mechanism.'. To fill this gap, this study investigated whether and how farmers' cognition of COVID-19 outbreak affects their willingness to produce green production. Based on the existing research, the marginal contribution of this paper is to analyze and explore the mechanism of green production willingness generation from a new perspective of COVID-19 risk perception. By the survey data in rural areas of China, the relationship between People's awareness of Covid-19 and their willingness to green production was verified. This study is beneficial to the promotion and development of green and sustainable agriculture in the later stage of the epidemic.'

2. Materials and methods

2.1. Research hypothesis

The Cognitive Theory proposed by E.C.Tolman in 1932 holds that the body will have new understandings and new views on the current situation and problems, and will make concrete and visualize the understanding of the situation, thus producing cognition (Bandura, 1986). Cognitive process is a complete set of information processing system, including cognitive operations such as the acquisition, coding, storage, extraction and use of information (Mathews and MacLeod, 1994). When people are in the scene of a COVID-19 outbreak, individuals acquiring external stimuli will encode and store information, forming an overall understanding of the COVID-19 outbreak after its extraction and use by the brain. The stronger the individual cognition, the higher the degree of psychological processing of the risk, causality and market demand of the epidemic itself (Fiske and Taylor, 1991). As a rational economic farmer (Finucane et al., 2000), the more likely it is to develop the willingness to produce green products driven by market demand after the balance of economic interests. On the other hand, according to "Gaia hypothesis", the COVID-19 outbreak is caused by human ecological destruction, which enables people to reflect on whether their own initiative behavior meets ecological standards, that is, to promote people's ecological reflection (Bandura, 2001), and promote the transformation of farmers' production intentions in the concept of "harmony between man and nature".

Therefore, hypothesis 1 is proposed that there is a positive relationship between COVID-19 cognition and farmers' willingness of green production.

The Stimulus-organism-response (SOR) model was proposed by environmentalists Mehrabian and Russell to explore the effects of stimuli on individual emotional responses (Mehrabian and Russell, 1974). It has been widely used in many research fields, such as subjective cognition, risk perception, mental state and behavioral intentions (Su and Swanson, 2017; Bauer, 1960; Flavian et al., 2019). The COVID-19 outbreak, especially the transmission rate, mortality and sequelae of the virus, has had a huge impact on individual cognition, forming a "source of stimulus". Furthermore, it affects people's attitude, judgment and emotion towards the epidemic, thus forming the "body" structure of the SOR system-risk perception (Slovic, 1987).

Therefore, hypothesis 2 is proposed that there is a positive relationship between farmers' cognition and risk perception of COVID-19 outbreak.

According to Even System Theory, the temporal and spatial attributes of the event as well as the intensity attribute are used to measure the individual's perceived risk intensity in this study (Morgeson et al., 2015), and reflects the "level of stimulation" by the strength of risk perception. In the case of a major public health emergency such as the COVID-19 outbreak, the perceived threat of the outbreak will prompt people to improve their ability to cope with the risk, and the individual's risk perception of the time, space, and intensity of the outbreak will produce a systematic "response" to cope with the risk (Reznik et al., 2021; Coccia, 2020). In addition to self-protection behaviors such as health protection and isolation and prevention (Joop, 1996; Lu et al., 2018), may also increases current health investment through green production (Wang et al., 2021; O' Connor and Assaker, 2021). Accordingly, the following hypothesis is proposed.

Hypothesis 3. There is a positive relationship between farmers' risk perception of COVID-19 outbreak and green production willingness.

Hypothesis 4. Farmers' risk perception of COVID-19 outbreak may play a role in mediating the impact of cognition on green production willingness.

In view of this, this study proposes the research idea of farmers' cognition of COVID-19 outbreak → risk perception → willingness of green production based on Cognitive Theory, Event System Theory and SOR model, and a theoretical model of the formation of farmers' willingness of green production in the context of the COVID-19 outbreak was constructed (Fig. 1).

2.2. Sources of date

The data were collected and counted in August 2020 by a team of 22 teachers and graduate students from the School of Management, Sichuan Agricultural University. The survey was conducted in rural areas of Chengdu, Nanchong, Neijiang and Yibin, and 4–8 townships were randomly selected in each sample county, followed by 1–2 villages in each sample township and 5–10 villages in each sample village. In each sample village, 5–10 farming households were randomly selected as respondents. A total of 584 households were selected for the survey, distributed among 73 villages in 52 townships. Each household was surveyed by one adult who was familiar with the basic conditions of the household. The survey included farmers' cognition of COVID-19 outbreak, risk perception, willingness of green production, and their own characteristics and family endowment. A total of 540 valid questionnaires were obtained with a validity rate of 92.64% after post-testing and collation.

2.3. Variable definition and description

2.3.1. Explained variable

The explained variable in this paper is farmers' willingness of green production, it is a kind of behavior intention that the farmer carries on the green production. And refer to the relevant research (Li et al., 2020; Peng et al., 2022), the questionnaire is based on " Are you willing to

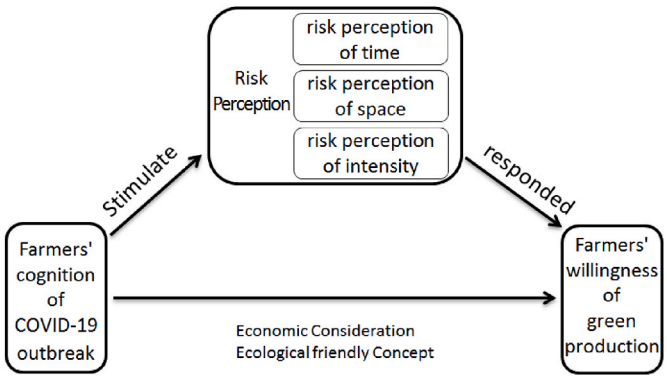

Fig. 1. Theoretical model of the formation of farmers' willingness of green production.

participate in green production after the COVID-19 outbreak?" Values is 1–5. On the whole, the surveyed farmers have high green production willingness, and the average willingness to participate is 3.436.

2.3.2. Explanatory variable

Refer to the relevant literature of the COVID-19 survey (Wang et al., 2020; Hou et al., 2021), farmers were surveyed as the item " Do you understand the infection rate and case fatality rate of COVID-19 outbreak?". Values is 1–5. On the whole, the average degree of the sample peasant's cognition of COVID-19 outbreak was 3.308.

2.3.3. Intermediate variable

According to the above theory, this paper divides farmers' risk perception of COVID-19 into three dimensions: time risk perception, spatial risk perception, and intensity risk perception. It includes three questions: " Do you think the duration of COVID-19 outbreak is unpredictable?"" Are you worried about the route of COVID-19 transmission?"" Are you afraid of the COVID-19 outbreak?". Values is 1–5. The AHP hierarchical analysis method is used to assign the three indicators, see Table 1. Overall, the sample farmers have the strongest sense of the time risk of the epidemic, with a weighted average of 3.806.

2.3.4. Other control variables

Referring to the green production willingness of farmers (Yu et al., 2020; Luo et al., 2022a,b; Gao et al., 2018), we control for nine variables including farmers' gender to explore the effect of farmers' cognition of COVID-19 outbreak on willingness of green production and their mechanisms of action in this paper. The specific meanings and values of the variables are shown in Table 2.

2.4. Research method

2.4.1. Analytic hierarchy Process (AHP)

The key to assessing the perceived level of risk perception of COVID-19 outbreak is empowerment. To avoid the limitations of Delphi and factor analysis methods, the former being too subjective and the latter focusing on quantitative variables (Sajadian et al., 2017; Hill et al., 2018). AHP is a combination of qualitative and quantitative, systematic, hierarchical analysis method. This method is characterized by making use of less quantitative information to make the thinking process of decision-making mathematically based on the in-depth study of the essence, influencing factors and their internal relations of complex decision-making problems, therefore, a simple and convenient decision-making method is provided for complex decision-making problems with multi-objectives, multi-criteria or without structural characteristics. People's risk perception of epidemic is a multi-dimensional and multi-faceted problem, which includes not only time, space, but also influence intensity. It is a complex system that is difficult to be completely quantified, aHP is a model and method that can make decision in this kind of complex problem. This study used AHP hierarchical analysis to assign weights to the variables, and invited six experts, including psychologists, epidemic prevention and control personnel, and professional farmers, to rate the relative importance of each variable according to A.L. Saaty's 1–9 scale. The discriminant matrix was obtained after processing, and a comprehensive evaluation of farmers' perceived risk of epidemic was obtained by assigning weights to each variable.

2.4.2. Ordered probit model

Since the explanatory variables are ordered variables from 1 to 5, an oprobit model was used to estimate the parameters of the farmers' cognition of COVID-19 outbreak and willingness of green production. The empirical model was set as follows.

$$\boldsymbol{willingness}_i = \boldsymbol{\alpha}_0 + \boldsymbol{\alpha}_1 \boldsymbol{cognition}_i + \boldsymbol{\alpha}_2 \boldsymbol{X}_i + \boldsymbol{\mu}_i \tag{1}$$

Among them, $\boldsymbol{willingness}_i$ indicates farmers' willingness of green production. $\boldsymbol{cognition}_i$ is farmers' cognition of COVID-19 outbreak, $\boldsymbol{X}_i$ is a series of control variables, including own characteristics and family endowment. $\boldsymbol{\mu}_i$ is a random interference term. Assuming $\mu \sim N\ (0,\ 1)$ distribute, the Oprobit model can be represented as :

$$\boldsymbol{P}(\boldsymbol{willingness} = \boldsymbol{1}|\boldsymbol{x}) = \boldsymbol{P}(\boldsymbol{willingness}^* \le \boldsymbol{r}_0|\boldsymbol{x}) = \boldsymbol{\varphi}(\boldsymbol{r}_0 - \boldsymbol{\alpha}_1 \boldsymbol{cognition}_i - \boldsymbol{\alpha}_2 \boldsymbol{X}_i)$$

$$\boldsymbol{P}(\boldsymbol{willingness} = \boldsymbol{2}|\boldsymbol{x}) = \boldsymbol{P}(\boldsymbol{r}_0 < \boldsymbol{willingness}^* \le \boldsymbol{r}_1|\boldsymbol{x}) = \boldsymbol{\varphi}(\boldsymbol{r}_1 - \boldsymbol{\alpha}_1 \boldsymbol{cognition}_i - \boldsymbol{\alpha}_2 \boldsymbol{X}_i) - \boldsymbol{\varphi}(\boldsymbol{r}_0 - \boldsymbol{\alpha}_1 \boldsymbol{cognition}_i - \boldsymbol{\alpha}_2 \boldsymbol{X}_i)$$

$$\boldsymbol{P}(\boldsymbol{willingness} = \boldsymbol{5}|\boldsymbol{x}) = \boldsymbol{P}(\boldsymbol{r}_3 \le \boldsymbol{willingness}^*|\boldsymbol{x}) = \boldsymbol{1} - \boldsymbol{\varphi}(\boldsymbol{r}_3 - \boldsymbol{\alpha}_1 \boldsymbol{cognition}_i - \boldsymbol{\alpha}_2 \boldsymbol{X}_i) \tag{2}$$

In Equation (2), the parameter to be estimated is $\boldsymbol{r}_0 < \boldsymbol{r}_1 < \boldsymbol{r}_2 < \boldsymbol{r}_3$, The value of $\boldsymbol{willingness}_i$ ranging from 1 to 5 represents the intensity of farmers' willingness of green production. By constructing the likelihood function of the green production willingness of each surveyed farmer, the model was then parameter-estimated by using the maximum likelihood method.

2.4.3. Mediator effect model

To further verify whether risk perception plays a significant mediating role between farmers' willingness of green production and COVID-19 outbreak perception. Referring to the mediation effect test method proposed by MacKinnon et al. (2007), the mediation effect model is set as follows:

$$\boldsymbol{willingness}_i = \boldsymbol{\alpha}_0 + \boldsymbol{\alpha}_1 \boldsymbol{cognition}_i + \boldsymbol{\alpha}_2 \boldsymbol{X}_i + \boldsymbol{\varepsilon}_i \tag{3}$$

$$\boldsymbol{perception}_i = \boldsymbol{\beta}_0 + \boldsymbol{\beta}_1 \boldsymbol{cognition}_i + \boldsymbol{\alpha}_2 \boldsymbol{X}_i + \boldsymbol{\mu}_i \tag{4}$$

$$\boldsymbol{willingness}_i = \boldsymbol{\gamma}_0 + \boldsymbol{\gamma}_1 \boldsymbol{cognition}_i + \boldsymbol{\gamma}_2 \boldsymbol{perception}_i + \boldsymbol{\alpha}_2 \boldsymbol{X}_i + \boldsymbol{\varphi}_i \tag{5}$$

Among them, $\boldsymbol{perception}_i$ is risk perception, $\boldsymbol{\alpha}_1$ in (3) reflects the total effect of farmers' cognition on willingness of green production, $\boldsymbol{\beta}_1$ in (4) indicates the impact of farmers' cognition on the risk perception of intermediary variable, and γ_1、 γ_2 in (5) indicates the direct effect of farmers' cognition and risk perception on the willingness of green production respectively. Substituting (4) into (5) can obtain the intermediary effect $\beta_1\gamma_2$ of cognition, in other words, the indirect impact of farmers' cognition on willingness of green production through the intermediary variable risk perception. Meanwhile, the ratio of the mediation effect to the total effect is used to reflect the relative size of the mediation effect, that is $\beta_1\gamma_2/\ \alpha_1$.

2.4.4. Preliminary tests

In fact, before empirical evidence, we must pass rigorous preliminary tests to verify the scientific nature and validity of the investigation and empirical evidence. These tests are necessary to detect the existence of variable consistency, collinearity, and heteroscedasticity. To this end,

Table 1
Weighted results of COVID-19 outbreak.

Variable	Dimension	Indicators	Mean value	Standard deviation	Weight
Risk Perception of COVID-19	Risk perception of time	Duration of COVID-19 is considered unpredictable	4.301	1.204	0.557
	Risk perception of space	Worried about the route of COVID-19 transmission	3.311	1.166	0.123
	Risk perception of intensity	Afraid of the COVID-19 outbreak	3.388	1.081	0.320

Note: The data in the table are rounded off, and the same is true in the table below.

Table 2
Meaning and assignment of variables.

Type of Variable		Variable	Meaning and Assignment	Mean value	Standard deviation
Explained variable		Farmers' willingness of green production	Not willing = 1; Reluctantly = 2; Generally = 3; More willing = 4, Very willing = 5	3.436	1.333
Explanatory variable		Cognition of COVID-19 outbreak	Knowledge of COVID-19 infection rate and fatality rate: Ignorance = 1; Unknown = 2; General = 3; Comparative understanding = 4, Understanding = 5	3.308	0.736
Intermediate variable		Risk perception of COVID-19 outbreak	Empowerment result of the three sense of risk perception dimensions: time, space and intensity	3.806	0.516
Control variables	Own characteristics	Sex	Female = 0, male = 1	0.612	0.488
		Age	Actual age/year	54.022	10.368
		Education level	Actual years of education/year	7.298	3.598
	Family endowment	Family location	Home is about/km from the nearest town	4.428	3.858
		Family population size	Total family population/person	4.190	1.687
		Family Member Political Identity	Whether there is a cadre at home: no = 0, is = 1	0.259	0.438
		Health level of the family members	Very low = 1; low = 2; generally = 3; higher = 4, very high = 5	3.935	0.790
		Investment risk tolerance	Very low = 1; low = 2; generally = 3; higher = 4, very high = 5	2.482	0.607
		Neighborhood trust	Very low = 1; low = 2; generally = 3; higher = 4, very high = 5	3.850	0.851

the design of the existing study is referenced (Fuinhas et al., 2021), and some preliminary tests are performed, as shown in Table 3 below. The results showed that the data of this study passed the preliminary test.

Then, the design of this study will follow the following conceptual framework (see Fig. 2).

We used the econometric software Stata 17.0 in our study. Indeed, the Stata commands used in this study included summarize, vif, reg, estat imtest, white, oprobit, margins, cmp, ivprobit, sgmediation, bootstrap. These commands were used to realize the preliminary tests and the model estimations.

3. Empirical results

In order to explore the relationship between farmers' cognition of COVID-19 outbreak, risk perception, willingness of green production and their interaction mechanism. First, the Oprobit benchmark model was used for preliminary discussion. Second, after controlling for the endogeneity of the model, further regressions were performed using the IV-Oprobit model, and finally mediating effects were tested.

3.1. The impact of farmers' cognition of COVID-19 outbreak on willingness of green production

Model (1) in Table 4 examines the direct effect of cognition of COVID-19 outbreak on farmers' willingness of green production, the results show that, controlling for a range of other variables, COVID-19 cognition has a significant positive effect on farmers' willingness, and this is significant at the 1% confidence level, this indicates that the higher the level of COVID-19 cognition, the more likely farmers have the willingness to green production. Since both COVID-19 cognition and farmers' willingness to green production may have the same effect due

Table 3
Preliminary tests.

Test	Reference	Description
Cronbach's α	Hays et al.	To evaluate the consistency of continuous variables and ordinal categorical variables.
Variance Inflflation Factor (VIF)	Belsley et al.	To measures multicollinearity in a regression analysis.
White test	Halbert White.	To check for heteroscedasticity
Confirmatory Factor Analysis (CFA)	Malaquias et al.	To test whether the tool correctly detects the extent of the underlying trait
Harman's single-factor test	Podsakoff et al.	To determine whether there are serious common method deviations and ensure the reliability of hypothesis test

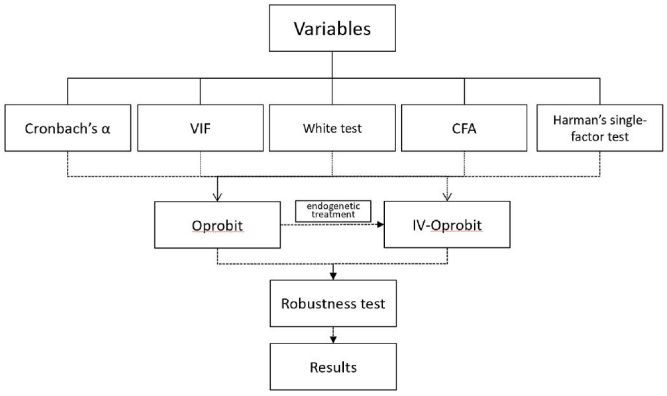

Fig. 2. Conceptual framework.

to common reasons such as farmers' individual understanding and thinking ability, the instrumental variables method (IV-Oprobit) was used to correct the model estimation results in order to solve the problem of biased estimation results caused by endogeneity and to obtain consistent unbiased estimates. Based on the condition that the instrumental variables should be highly correlated with the endogenous explanatory variables but not with the nuisance terms, neighbors' cognition of COVID-19 outbreak was selected as the instrumental variable in the model. Neighbors' cognition affect the interviewed farmers due to social network relationships and are strongly correlated. However, it is clear that this indicator is not directly related to respondents' willingness of green production. Therefore, this variable meets the correlation and exogeneity assumptions of instrumental variables. Two models were constructed to test the exogeneity and validity of the instrumental variable. The results showed that the instrumental variables were insignificant for farmers' willingness to green production and significant for COVID-19 cognition, and the correlation coefficient test also supported the results, indicating that the instrumental variables were set reasonably.

Model (2) in Table 4 shows the results of retesting 'cognition of COVID-19 outbreaks on farmers' willingness of green production using the IV-Oprobit model, the model passed the likelihood ratio test, the lnsig_2 value was −0.758, the two-stage estimation of the model was significant, and the model passed the atanhrho_12 test, indicating that the use of the CMP method in the above model is superior to model (1). Oprobit estimation, therefore, the use of instrumental variable in the ordered choice model is valid. Model (3) shows the results of estimating the marginal effects corresponding to the regression. From the results,

Table 4
The effect of cognition of COVID-19 outbreak on 'farmers' willingness of green production.

Variables	Model (1) Oprobit	Model (2) IV-Oprobit	Model (3) Boundary effects/%				
			Not willing	Reluctantly	Generally	More willing	Very willing
Cognition of COVID-19 outbreak	1.320***	1.408***	−0.134***	−0.140***	−0.054***	0.029***	0.299***
	(0.101)	(0.196)	(0.013)	(0.013)	(0.007)	(0.011)	(0.020)
Control variables							
Sex	0.040	0.020	−0.004	−0.004	−0.002	0.001	0.009
	(0.103)	(0.110)	(0.010)	(0.011)	(0.004)	(0.002)	(0.023)
Age	−0.002	0.000	0.000	0.000	0.000	0.000	0.000
	(0.006)	(0.007)	(0.001)	(0.001)	(0.000)	(0.000)	(0.001)
Education level	0.045***	0.040**	−0.005***	−0.005***	−0.002***	0.001**	0.040***
	(0.016)	(0.019)	(0.002)	(0.002)	(0.001)	(0.001)	(0.004)
Family location	−0.034***	−0.029*	0.003***	0.004***	0.001**	−0.001**	−0.030***
	(0.014)	(0.017)	(0.001)	(0.001)	(0.001)	(0.000)	(0.003)
Family population size	−0.064**	−0.062**	0.006	0.007**	0.003**	−0.001**	−0.014**
	(0.029)	(0.029)	(0.003)	(0.003)	(0.001)	(0.001)	(0.007)
Family Member Political Identity	−0.088	−0.105	0.009	0.009	0.004	−0.002	−0.020
	(0.111)	(0.116)	(0.011)	(0.012)	(0.005)	(0.003)	(0.025)
Health level of the family members	−0.143**	−0.146**	0.145**	0.152**	0.006**	−0.003**	−0.032**
	(0.063)	(0.063)	(0.007)	(0.007)	(0.003)	(0.002)	(0.014)
Investment risk tolerance	−0.101	−0.095	0.010	0.011	0.004	−0.002	−0.023
	(0.080)	(0.081)	(0.008)	(0.009)	(0.003)	(0.002)	(0.018)
Neighborhood trust	−0.019	−0.019	0.002	0.001	0.001	0.000	−0.004
	(0.059)	(0.059)	(0.006)	(0.002)	(0.002)	(0.001)	(0.013)
Pseudo R^2 /lnsig_2	0.239	−0.758***					
		(0.030)					
LRchi^2/atanhrho_12	393.36	−0.053**					
	(0.000)	(0.105)					
Log likelihood/waldchi^2	−626.981	1116.48					
		(0.000)					

Note: * * * and * * indicate the significance levels of 1% and 5%, respectively, and the numbers in parentheses are the robust standard error of the coefficient, and the same is true in the table below.

the effect of COVID-19 cognition on farmers' willingness of green production was similar to the baseline regression results reported in model (1) in terms of direction and significance, verifying the positive effect of COVID-19 cognition on farmers' willingness of green production. In addition, the estimation of marginal effects in model (3) shows that the probability of "very willing" participation in green production increases by 29.9% for each unit increase in farmers' COVID-19 cognition after controlling for endogeneity, which corroborates with the previous inference and proves the proposed hypothesis 1.

Possible explanations are that, on the one hand, the long duration of the epidemic has aroused the public' s desire and demand for green and healthy products', the higher the farmers' condition of the epidemic, the better they can grasp the market demand and consumption habits, and economic benefits are the key consideration for farmers as rational economic people to make production decisions, which will prompt them to choose more efficient production methods. On the other hand, during the period of normalization of epidemic prevention, farmers will think more rationally about the nature of the epidemic and how to deal with it after experiencing emotional fluctuations, and are more likely to appreciate that the harmony between human beings and nature is the basic relationship between human society and transition from immediate coping measures such as wearing masks to long-term coping measures such as protecting the ecological environment, which is consistent with the conclusions derived from the previous theory.

As for other control variables, 'education level, distance from home to town, number of household members, and health of household members had different levels of significant effects on farmers' willingness of green production. Possible explanations are: the more educated and literate farmers are, the better their understanding and cognitive ability, the more likely they are to perceive market changes and pursue ecological health after the epidemic, and thus develop the willingness to produce green. The farther the farmers' homes are from the settlement center, the less information is available, and the more difficult it is for them to have green ecological awareness.

3.2. Influence of farmers' cognition of COVID-19 outbreak on farmers' willingness of green production by different generations

There are significant differences in values and preferences among generations of farmers, and different values influence judgments and behaviors (Lyons and Kuron, 2014; Luo et al., 2022). According to the academic standard of dividing the old and new generations farmers and taking into account the actual situation in rural areas, this paper uses 50 years old as the dividing line to classify the new generation and the old generation farmers, and conduct Oprobit and IV-Oprobit regressions on the effect of farmers' cognition of COVID-19 outbreak on farmers' willingness of green production for the two generations respectively. As shown in Table 5, after controlling for the endogeneity of the model, cognition of COVID-19 outbreaks had a significant positive effect on farmers' willingness of green production in both the new and old generations farmers, and more significantly in the old generation. The possible explanation for this is that although the older generation farmers are weaker than the younger ones in terms of risk perception, they are less able to make a living and have a stronger dependence on agriculture, and when they perceive the change in market demand

Table 5
The effect of different generations of 'farmers' cognition of COVID-19 outbreak on their willingness of green production.

Variables	Old generation farmer		New generation farmer	
	Oprobit	IV-Oprobit	Oprobit	IV-Oprobit
Cognition of COVID-19 outbreak	1.374***	2.032***	1.203***	1.517***
	(0.130)	(0.154)	(0.173)	(0.229)
Control variables	Controlled	Controlled	Controlled	Controlled
Sample size	321	321	219	219
Pseudo R^2	0.237	–	0.172	–
Waldchi^2/LRchi^2	237.89	1074.79	96.27	492.78
	(0.000)	(0.000)	(0.000)	(0.000)
Log likelihood	−383.747	−582.690	−231.332	−327.849

caused by the epidemic, they are more likely to opt to participate in green production based on increasing farm income and protecting their home environment.

3.3. Mediation effect test

To confirm the theoretical analysis that risk perception plays a mediator role in this effect, we analyzed the mediating mechanism through which cognition of COVID-19 outbreak affects willingness by changing risk perception, and analyzed it by referring to the existing mediating effect test method (MacKinnon et al., 2007), the results are shown in Table 6. The regression analysis of farmers' COVID-19 cognition and risk perception using model (4) revealed a significant contribution of COVID-19 cognition to risk perception with a coefficient of 0.272 and passed the significance test at the 1% level, and hypothesis 2 was tested. Model (5) was used to examine the effect of farmers' risk perception on willingness of green production, and the results showed that the risk perception had a significant positive effect on willingness, and it was significant at 1% level of significance, and Hypothesis 3 was tested. Model (6) introduced independent and intermediate variable, and the estimated coefficients of both COVID-19 cognition and risk perception were significantly positive. The results showed that the effects on farmers' willingness of green production were significant at 1% and 5% significance levels, respectively, indicating that farmers' risk perception played a partially mediation effect between COVID-19 cognition and willingness of green production.

The Sobel test (Sobel method) and the self-sampling test (Bootstrap method) can calculate the mediation effect ratio more accurately. The purpose of this method is to test the product of coefficient ab. The advantages of this method are obvious, more mediating effects can be detected than the stepwise regression coefficient method. At present, it is widely used in the research of mediating effect test (Luo et al., 2022a, b). Sobel method and Bootstrap method were used to test the risk perception mediation effect, which was significant at the 1% level, and the size of this mediation effect was about 0.040, accounting for about 13.59% of the total effect, further confirming the robustness of the mediation effect. This suggests that risk perception plays a partially mediating role in the process of cognition of COVID-19 outbreak influencing willingness of green production, and Hypothesis 4 was verified. Specifically, as farmers' awareness of the epidemic increases, so does their level of risk awareness. Out of an instinctive response to enhance their risk resistance, farmers generally choose green production as the most convenient and less costly way to invest in health, both to increase consumption of healthy food to improve body immunity, and to reduce the damage caused to their bodies by reducing the use of chemical pesticides and fertilizers in the periphery.

Table 6
Mediation effects of 'farmers' risk perceptions.

Variables	Model (4) Risk perception (Oprobit)	Model (5) Willingness of green production (Oprobit)	Model (6) Willingness of green production (IV-Oprobit)
Cognition of COVID-19 outbreak	0.624***	–	1.372***
	(0.086)		(0.213)
Risk perception	–	0.546***	0.183*
		(0.100)	(0.124)
Control variables	Controlled	Controlled	Controlled
Sample size	540	540	540
Waldchi^2/LRchi^2	132.41	242.09	1240.34
	(0.000)	(0.000)	(0.000)
Log likelihood	−2115.649	−702.616	−960.769
lnsig_2	–	–	−0.795***
			(0.030)
atanhrho_12	–	–	−0.060**
			(0.109)

3.4. Robustness test

To further ensure the reliability of the study findings, sample robustness tests will be conducted on the main effects in terms of sample and model, as detailed in Table 7.

On the one hand, sample robustness tests are performed. Since the effect of cognition of COVID-19 outbreak on farmers' willingness to produce green products is being explored, the current behavioral decisions of farmers over 80 years old are less related to cognition of COVID-19 outbreak due to their significantly reduced cognitive ability and perception, Therefore, excluding this group of farmers, the results are still significant at the 1% level, as shown in columns (1) and (2) of Table 7, indicating that the sample is robust.

On the other hand, robustness of the model was tested. The Probit and IV-Probit models were estimated after classification as dichotomous variables. Based on the previous paper, we divided farmers' willingness to green production into two groups: those who were "unwilling" and "reluctantly" were classified as the "unwilling" sample group, and those who were "generally", "more willing" and "very willing" were classified as the "willing" sample group. At this point, the explanatory variables are changed from "ordered" to "dichotomous" variables, and the IV-Probit model is chosen for robustness estimation (see columns (3) and (4) of Table 7). The regression results of the robustness tests are generally consistent with the previous ones, this indicates that the estimation results are robust.

4. Discussion

4.1. Similarities and differences with existing research

The outbreak of Covid-19 has had a tremendous impact on many industries and fields, such as agriculture, ecological environment, consumer economy and mental health, behavioral intentions for green sustainable production have changed (Grigorescu et al., 2022; Adithya et al., 2022; Wang et al., 2021). As Shakil et al. (2020) suggested that there is an intrinsic link and impact between the spread of Covid-19 and related phenomena and environmental issues, Marazziti et al. (2021) found that people learn to reflect on past lack of protective behavior towards nature and the environment in an outbreak, Hall et al. (2020)

Table 7
Robustness test results.

Variables	(1) Oprobit	(2) IV-Oprobit	(3) Probit	(4) IV-Probit
Cognition of COVID-19 outbreak	1.335***	1.829***	1.694***	2.368***
	(0.107)	(0.137)	(0.168)	(0.195)
Sex	0.006	−0.116	0.219	−0.223
	(0.109)	(0.111)	(0.153)	(0.152)
Age	−0.002	0.011	0.002	0.020**
	(0.006)	(0.006)	(0.008)	(0.008)
Education level	0.060***	0.025**	0.029	−0.020**
	(0.017)	(0.019)	(0.024)	(0.024)
Family location	−0.036***	−0.007**	−0.006	0.041**
	(0.015)	(0.016)	(0.021)	(0.022)
Family population size	−0.075***	−0.055**	−0.018	−0.002
	(0.031)	(0.031)	(0.044)	(0.041)
Family Member Political Identity	−0.116	−0.205	0.098	−0.062
	(0.118)	(0.118)	(0.181)	(0.184)
Health level of the family members	−0.122**	−0.139**	−0.155	−0.104
	(0.068)	(0.067)	(0.100)	(0.093)
Investment risk tolerance	−0.154	−0.103	−0.043	0.019
	(0.085)	(0.085)	(0.125)	(0.110)
Neighborhood trust	−0.051	−0.047	0.068	0.704
	(0.061)	(0.061)	(0.098)	(0.080)
Pseudo R^2	0.247	–	0.456	–
LRchi^2/waldchi^2	364.26	1554.38	303.26	224.36
	(0.000)	(0.000)	(0.000)	(0.000)
Log likelihood/Log pseudo likelihood	−556.750	−838.808	−181.105	−496.553

noted that people are beginning to produce and operate in more environmentally friendly and eco-friendly ways to prevent further and more frightening epidemics in the future. This research is in these discourses foundation, carries on the extension and the expansion. Similar to the existing findings (Brenna et al., 2021; Muhammad et al., 2020; Ben et al., 2020), we also found a positive and significant effect relationship between COVID-19 and people's ecological conservation behavior intentions. But this research goes further. Because the concept of ecological protection is too broad, we narrow it down to the scope of agricultural green production, and focus on the investigation and empirical study of farmers' green production intention, it turns out that the more people know about COVID-19, the more likely they are to be green in agriculture.

The design of this study is also significantly different from previous literature like Martey et al. (2022), farmers' perceptions of COVID-19 shocks can affect their likelihood and intensity of adopting structural sustainable action plans in agricultural production measures, without attention to the mediating effects that may exist therein. Zhou et al. (2022) found that in the context of COVID-19, farmers' production intentions and livelihood decisions are affected, with a key factor stemming from the shortage of agricultural Means of production due to epidemics. Teng et al. (2022) found that farmers' green production practices became more active during COVID-19, with individual characteristics, government guidance, industry organization, and market regulation being key factors in the impact. Different from them, we found that farmers' risk perception of Covid-19 is a mediating variable of their green production behavior.

O' Connor and Assaker (2021) empirically verified the mechanism by which people's risk perception influences their future environmental behavior. Similarly, this study also confirmed the effect of COVID-19 cognition on the intention of environmental behavior and its internal mechanism. However, the difference is that the former uses structural equation model, and we use CMP method to better control the endogeneity problem through the use of instrumental variables, and the conclusion is more reliable. In addition, unlike existing studies, which mainly include the perception of the health risks of COVID-19 or those around it, we use event systems theory to provide a more comprehensive and accurate interpretation of risk perception, which measures the risk perception of COVID-19 from three aspects: the duration of the outbreak, the space of transmission and the intensity of transmission.

4.2. Policy recommendations

Under the dual background of COVID -19 and sustainable development of agriculture, the policy made by countries around the world still has some deficiencies in the face of this brand-new proposition. For example, the government has not done enough to raise awareness among farmers about the protection of the ecological environment, and some farmers do not have enough awareness of the intrinsic relationship between COVID-19 and the ecological environment, and there are no targeted education programmers for different groups to understand it in depth. Because of their own vulnerability, some government officials have not put farmers in the main consideration of policy design, especially those poor farmers with low level of education who are far away from cities. Secondly, due to the inconvenience caused by COVID-19, the monitoring system for green agricultural products in most developing countries is not perfect, and the green agricultural market is not transparent, there is no green trading platform that everyone can trust.

Based on the literature review and empirical analysis, this paper proposes the following policy recommendations. First of all, the use of rural community workers and teachers resources, in the long-term context of COVID-19 to strengthen environmental protection in the promotion and education. Taking the cultivation of farmers' ecological and environmental responsibilities and the popularization of ecological and environmental protection knowledge as a solid foundation for green agricultural production, increasing the efforts of publicity and education, and designing differentiated publicity and education programmers for different generations and levels of education, the focus is on helping the less well-endowed farmers, especially those who are far away from cities and have low levels of education, and actively guiding them to participate in green production through publicity and explanation. Second, attract civil society capital to establish a market for green agricultural products during the COVID-19 period and improve the testing and promotion mechanism for green products. We will strengthen the marketing and reporting of green agricultural products on wechat and other social media platforms, and establish a platform for green marketing, green buying, and green agricultural products trading that consumers can fully trust, for the rural green production to provide a good trading environment and public services support. Third, through the existing education system and media, multi-channel to enhance the overall level of risk perception of farmers. We should interpret the relationship between the epidemic and the ecological environment from the perspective of"Human community", help farmers to improve their awareness of the risk of COVID-19, guide them to increase their current health investment, and improve their ability to resist risks, continuously strengthen the internal motivation of participating in green production. Finally, investment in research and development of agricultural science and technology should be increased, and the use of rapidly developing sensors to implement an automated green planting management system should help farmers to monitor, produce and optimize procedures in real time, increase productivity and profitability with small investments.

4.3. Limitations and future recommendations

One limitation of this study is that Covid-19 has a wide range of impacts, and the number of affected farmers is difficult to estimate, the results would be more scientific and universal if substantial data from multiple countries were available for empirical purposes. In addition, we only focus on the current situation of farmers' green production intention during the COVID-19 period, but ignore the farmers' continuous intention, which is more likely to promote people's green production behavior finally. These limitations are the result of unexpected challenges that arose during our initial choice of how to design the study, and would be of greater research interest if these challenges could be overcome.

COVID-19 clearly exposes all the vulnerabilities and inadequacies of the ecosystem, and at the same time, it highlights our error and neglect of the catastrophes caused by environmental pollution and the consequences of human non-sustainable activities, increasing the possibility of virus transmission to humans. In order to maintain a balance between humans, animals and the environment on the basis of life on Earth, research in the field of Covid-19 and the resource environment should be deepened. On the basis of this paper, the future can also be in these directions further in-depth study. For example, COVID-19 studies the impact of farmers' ecological protection behavior, including farmers' green production behavior, green lifestyle and intentions. In addition, in the context of COVID-19, is there any deviation between the eco-environmental intentions of farmers and the real environmental behavior? What is the mechanism of action? The study of these problems needs us to explore further.

5. Conclusions

'It is time to understand more deeply the relationship between COVID-19 and the ecological environment, not only for the survival of human beings, but also for the maintenance of a balance between the biological and natural environment on the basis of life on Earth, otherwise there will be no future. The purpose of this study was to explore the influence of people's cognition on Covid-19's willingness to produce green agriculture and its potential mechanism. The current literature reports that an outbreak of Covid-19 may enhance people's perception of risk, with disturbances ranging from a mild negative

emotional response to overall mental health. At the same time, the virus pandemic has exposed the fragility and fragility of our ecosystems, prompting a rethink of traditional mode of production that are harmful to the ecology. Therefore, the purpose of this paper is to review the existing scientific literature on these variables by means of questionnaire survey and empirical analysis of Chinese farmers, and to propose and comment on the effects and mechanisms among them, the conditional mixing process (CMP) is used to overcome the endogenous problem of the empirical model and the Shandong stick test. The results showed that, first, Strengthening farmers' COVID-19 cognition can significantly increase their willingness to participate in green practices. Second, farmers' COVID-19 cognition significantly enhances their risk perception and thus their willingness to green production. Therefore, risk perception is an important mediator of this effect. Third, the analysis of intergenerational differences showed that the effect of cognition of COVID-19 outbreak on farmers' willingness of green production was significant for both the new and old generations.

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CRediT authorship contribution statement

Lei Luo: Conceptualization, Methodology, Software, Data curation, Writing – original draft, Validation. **Dakuan Qiao:** Methodology, Software, Data curation, Writing – original draft, Validation. **Lishuang Wang:** Data curation, Writing – original draft. **Ling Qiu:** Data curation, Writing – review & editing. **Yuying Liu:** Editing, Writing – review & editing. **Xinhong Fu:** Supervision, Validation.

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.

Data availability

The authors do not have permission to share data.

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