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REVIEW ARTICLE

Risk assessment and analysis of harmful residues in edible agricultural products in China—take Anhui Province as an example

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Abstract

The reforming and opening-up and the development of agricultural science and technology have brought about the rapid growth of China's food quantity and solved the problem that 20% of the world's population has enough to eat. At the same time, it also brings the problem of harmful residues in food. On the one hand, the Chinese government guides farmers to rationally use chemical fertilizers, pesticides, and veterinary drugs. On the other hand, in urban and rural school canteens and farmers' markets in third-tier cities, the implementation of pesticide residue detection system. Through the investigation of 24 kinds of edible agricultural products which are easy to produce harmful residues, and using a variety of statistical methods, the results showed that at present, the residues of harmful substances in edible agricultural products consumed by urban residents and school canteens in urban and rural areas have been well controlled, and the compliance rate is about 80%. The residues of harmful substances in edible agricultural products consumed by rural residents obviously exceed the standard. Taking rice production as an example, although farmers can reduce the risk of excessive pesticide residues in rice through rational application of pesticides, they are more worried about less application of pesticides and bear the risk of reducing rice production. Most farmers still choose to take the risk of excessive pesticide residues.

Keywords Edible agricultural products · Residue of harmful substances · Rapid detection · Production function · Comprehensive evaluation

Introduction

Edible agricultural products refer to primary food from agriculture, forestry, animal husbandry, sideline and fishery industries and food only after superficial processing, also known as raw food, including grain, vegetables, livestock and poultry meat, eggs, soy products, and fruits. Before the 1970s, due to the backward agricultural production, China's basic living materials had been in a state of insufficient supply, and it had always been the focus of the Chinese government's work to let the people have enough to eat. China's economic reforming and opening-up has promoted the development of agricultural science and technology and accelerated the process of agricultural mechanization. In 1979, the land contract responsibility system was fully implemented in rural areas, which released a large number of surplus labor force in rural areas and activated the rural economy. With the rapid development of the production level of edible agricultural products, grain and various agricultural related materials have gradually enriched, and the supply bills of various materials have been cancelled successively in the 1990s. China's population accounts for 20% of the world's total, and its cultivated land is less than 7% of the world's total. Food self-sufficiency has always been a major strategic issue related to social stability. "Who will feed China" has once become the focus of global public opinion. From 2004 to 2015, China's grain production increased from $4.31 \times 10^8 t$ to $6.21 \times 10^8 t$, achieving a "twelve consecutive increase" in grain production, laying a solid material foundation for the healthy development of China's economy in the new era (Sun and Wang 2018). The national

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"*Thirteenth Five-Year Plan*" proposes a "strategy to ensure basic self-sufficiency of grains and absolute safety of rations", which clearly states the importance of ensuring safe food production (Yang et al. 2019). However, the development of science and technology not only brings benefits to people, but also brings many negative effects, such as the application of chemical fertilizers and pesticides, which greatly improves the output of agricultural products, but excessive application will form harmful residues in food. In 2015, China's total use of chemical fertilizers and pesticides exceeded 60 million tons and 1.8 million tons, accounting for 7% of the world's arable land. However, China invested more than 33% of the world's total amount of chemical fertilizers and pesticides, which is three times of the world average level and two times of the developed countries in Europe and America (Zhang et al. 2019). Shijiazhuang Sanlu Group, which was exposed in September 2008, used toxic melamine to increase the detection value of protein in milk powder. Since then, it has revealed the inside story of someone using high technology to carry out food counterfeiting, for example, feed "vegetarian meat essence" and growth-stimulating hormone to breeding animals. In order to prevent the death of fish in the process of transportation, operators add copper sulfate in the water of fish culture. On June 11, 2020, CCTV2 "Economic Information Broadcast" column reported that the criminal gang used industrial dilute sulfuric acid and homemade acid preservative to soak fruit "rambutan" to prolong the preservation time, and was arrested by Hangzhou police. Food safety has been concerned by the general public. In February 2009, China promulgated the first "*Food Safety Law of the People's Republic of China*". Then, more than 12600 national and industrial standards for agriculture have been formulated, of which more than 52% are national standards, and more than 85% are pesticide and veterinary drug residue limit standards. *The maximum residue limits of pesticides in food* (GB2763-2014) specifies the maximum dosage and residue of 387 pesticides. Under the severe crackdown of the government, there are far fewer cases of drug abuse directly in food, but the problem food is still being detected. Food safety problems are mainly caused by excessive levels of chemical fertilizers, pesticides and veterinary drug residues in agricultural products, and there is no effective control method. For example, in June 2016, Jinan City of Shandong Province announced a batch of unqualified agricultural products: Malachite green (including recessive malachite green) was not qualified in one batch of *Acanthopanax japonicus* in Huaiyin District. Furazolidone metabolite (AOZ) was detected in a batch of pork tenderloin from Runhui supermarket in Tianqiao District. Salbutamol clenbuterol was detected in a batch of raw pork from Shandong Jinze technical school in Licheng District, and one batch of Zucchini in Gaoer central kindergarten, Zhonggong Town, Licheng District, was found to have pesticide residues exceeding the standard. On June 9, 2020, Dongguan City, Guangdong Province, sampled 8 vegetables from the canteen of a children's products Co., Ltd. with 2000 people (known as food safety level I) in Yinhe Industrial Zone, Qingxi Town. The results showed that the pesticide residues of red pepper, green pepper and celery were unqualified. On April 18, 2015, cctv13 reported that the research group of School of Public Health of Shanghai Fudan University has been monitoring the urine of more than 1000 school children aged 8 to 11 in Shanghai, Jiangsu and Zhejiang for more than 1 year. One antibiotic was detected in 58%, more than two antibiotics were detected in 1/4, and six antibiotics were detected in some samples. These include tylosin, chlortetracycline and enrofloxacin for livestock and poultry. It has become an objective fact that the residues of harmful substances in many edible agricultural products in China seriously exceed the standard.

In Europe and the USA and other developed countries, planting and breeding are generally operated by a small number of large farms or farms. The government mainly supervises and restricts the use of pesticides and veterinary drugs in the production process of farms and farms through professional associations. In particular, the food safety standards of European and American countries are relatively high, and the food violations detected will be severely cracked down (Bernd 2015). Many countries in the European Union carry out routine detection of pesticide residues in the market food. Most of the results show that 80% of the food has not been detected pesticide residues, 15–18% of the food can be detected pesticide residues less than the maximum limit, and only less than 3% (usually less than 1%) of the food pesticide residues exceed the maximum limit. As China's agriculture and aquaculture are mainly run by scattered farmers independently, it is difficult for the government to directly supervise the production process (Schreinemachers and Tipraqsa 2012). The land contract responsibility system has lost its superiority, and now it has become an obstacle to the further development of agriculture. To solve the problem of pesticide residues, the Chinese government controls the production and marketing of edible agricultural products: (1) The Ministry of Agriculture has formulated a series of policies to control illegal operation of chemical fertilizers, pesticides and veterinary drugs, such as pesticide and veterinary drug franchise license system. Standards for rational and precise use of chemical fertilizers and pesticides have also been formulated. (2) Around 2008, Tianjin, Beijing and other first-tier cities began to carry out random inspection of edible agricultural products in major agricultural markets, and indirectly supervise the quality of edible agricultural products through sales channels. However, this kind of food has a large market supply, a wide range of varieties, and many market operators. In fact, retailers are not very clear about whether the harmful substances in the daily wholesale food exceed the standard. Moreover, it is extremely difficult to accurately analyze the organic compounds.

Although the vast majority of harmful residues can be detected, the conventional detection of many residues requires expensive, large and cumbersome equipment, which requires skilled professional and technical personnel to operate. It can only be carried out in the laboratory, and it takes almost half a day for a sample to be accurately analyzed in the laboratory. So, at that time, only a few hundred cases were sampled every year in general cities, which was basically symbolic testing. In recent years, scientific and technological workers all over the world have explored some new rapid detection methods with strong specificity, high sensitivity, convenience, safety and low cost, such as enzyme inhibition method, immunoassay, biosensor and other rapid detection technologies for pesticide and veterinary drug residues, and the amount of samples extracted has greatly increased. At present, the "Smart Agricultural Trade Data Center" has been set up in the regular farmers' markets in China's third-tier cities and above, which can receive reports from consumers every day or randomly select some food stalls for rapid screening. After the rapid detection method, the negative samples can pass directly, and the names of qualified stalls and food can be published through video. The samples that are positive by the rapid detection method are generally tested again. For the food that is unqualified after three times of testing, the operator is required to explain the source and destroy it or dispose it innocuously under the supervision of the testing personnel. If the unqualified food is found, the operator may apply to send it to a professional laboratory for re-inspection. If the re-inspection is still unqualified, the re-inspection fee shall be borne by the applicant. In addition, the drug and food regulatory departments at all levels shall carry out sampling inspection and supervision on the food in the canteens of various schools and hospitals within their jurisdiction.

Research background

Brief description of relevant research literature

At present, the research on the residues of harmful substances in edible agricultural products mainly includes three aspects: (1) The harm of excessive application of chemical fertilizer. Nitrite and cadmium in fertilizer are the main culprits of cancer (Velthof et al. 2009). The composition of chemical fertilizer is monotonous. Even compound chemical fertilizer can only provide some kinds of main nutrients, but cannot provide all kinds of nutrients needed for crop growth. Long-term application of chemical fertilizer results in the lack of organic matter and trace elements in the soil, which affects the normal growth and development of plants (Sun 2010). Yan M. (2014) conducted an experiment on the effect of combined application of organic fertilizer and chemical fertilizer on rice, and concluded that the combined application of organic fertilizer and chemical fertilizer was not only conducive to soil fertility, but also improved the quality of rice, and the greater the proportion of organic fertilizer, the better the effect. Li Z. (2009–2012) conducted experiments on winter wheat and summer maize at the same time, using chemical fertilizer and organic fertilizer according to different proportions, the results showed that the yield of organic fertilizer combined with chemical fertilizer was better than that of chemical fertilizer alone, and the yield of winter wheat with 25% organic fertilizer was the highest, and that of summer maize with 50% organic fertilizer was the highest. (2) The problem of excessive application of pesticides. For example, Schreinemachers and Tipraqsa (2012), according to the data of pesticide application in various countries from 1990 to 2009 collected by the Food and Agriculture Organization of the United Nations (FAO), considered that the growth of pesticide application intensity was negatively correlated with the level of national economic development, the growth of pesticide application intensity in developed countries was slow, and the application intensity in some developed countries had begun to decline. Jacquet et al. (2011) studied the relevant policies of government intervention on farmers' pesticide application behavior, established a model to study the potential of pesticide reduction in France, and proposed that under the premise of ensuring that farmers' income is not affected, training and education can reduce the pesticide application by 10%, especially combined with long-term scientific and technological progress, the pesticide application in France may be reduced by 30%. Huang and Chen (2008) discussed the impact of farmers' technical information and preferences on pesticide application intensity. Wang and Gu (2013) conducted a survey on some vegetable farmers in Jiangsu Province. They believed that the benefits of pesticides from reducing the yield of vegetables were greater than the cost of pesticides. They also proposed that if the residues of pesticides in vegetables would reduce the price of vegetables, farmers might reduce the amount of pesticides. Tang et al. (2012) sprayed chlorothalonil and chlorpyrifos on cucumber in open air and greenhouse according to the recommended standard of the manual. The results showed that (a) pesticide residues were leaf > fruit > stem > root. (b) After 14 days, chlorothalonil and chlorpyrifos residues were 7.86 mg/kg and 1.01 mg/kg respectively, far exceeding the national standard of 5 mg/kg and 0.1 mg/kg; after 7 days in the open air, chlorothalonil and chlorpyrifos residues were 4.46 mg/kg and 0.22 mg/kg respectively, which were lower than the national standard. Zhang et al. (2011) conducted experiments on rice using a variety of pesticides. The results showed that (a) 80% of pesticide residues were concentrated in rice husk and rice straw. (b) The pesticide residues in rice were much lower when applied before heading than after heading. Fu (2014) concluded that the degradation rate of chlorothalonil in cucumber and tomato in spring was faster than that in autumn, mainly because the temperature in spring was gradually warmer and that in autumn was gradually cooler. Some scholars discussed the degradation law of pesticides in agricultural products, and found that the residue rate c of most pesticides in agricultural products and days after application t were in accordance with the negative exponential regression equation $C = C_0 e^{-kt}t$. For example, Feng et al. (2007) conducted a dynamic test of pesticide degradation on open-field cucumbers, using 4 insecticides chlorpyrifos, fenpropathrin, cypermethrin, and amacloprid and 3 fungicides chlorothalonil, thiophanate methyl, and copper oxychloride; as a result, the residue of each drug basically conforms to the negative exponential equation. For example, the residual rate equation of chlorpyrifos is $C = 1.5313e^{-0.7665t}$. Li et al. (2012) tested the dynamic changes of the residual rate of buprofezin in rice, simulated 5 models, and obtained the Rayleigh dynamic model with the highest accuracy $C = 0.47662t^{-0.21215t}e^{-0.01542t^2}$ (3) The residue of harmful substances in animal derived food. Cheng et al. (2017) discussed the issue of formaldehyde residues in aquatic products. He et al. (2013) discussed measures to ensure the safety of food of animal origin. However, no one has been involved in the assessment of the severity of harmful residues in edible agricultural products in China.

Agricultural production environment in Anhui Province

Anhui is located in Eastern China and is a typical inland province, straddling the Yangtze River and the middle and lower reaches of the Huai River. It connects with Jiangsu and Zhejiang in the east, Hubei and Henan in the west, Jiangxi in the south and Shandong in the north. The province has jurisdiction over 17 cities, including 104 districts (counties). The province can be roughly divided into five natural regions: Huaibei Plain, Jianghuai Hill, Dabie Mountain Area in West Anhui, Riverside Plain and Southern Anhui Mountain area. Plains, hills, and mountains each account for about one-third. Rich in agricultural resources and a large proportion of agricultural products, it is a typical agricultural province. According to the Provincial Statistics Bureau, the province has a land area of 139,600 km^2, including 88 million mu of arable land, 56 million mu of woodland, and 8.7 million mu of water surface for breeding. The province's permanent population is about 61 million, of which the rural population is about 53 million. The agricultural climatic conditions are suitable, the annual average temperature is 14–17°, and the annual rainfall is 700–1700 mm. There are abundant agricultural species resources, including 3200 species of wild plants and more than 500 species of wild animals. Anhui is a major grain-producing province in the country. The annual crop planting area exceeds 130 million mu, of which the area of grain crops accounts for more than 75%, and the total output is 35 million tons. The area ranks fourth in the country and the total output ranks 6–8 in the country. The main grain crops are wheat, rice, corn, soybeans, potatoes and other dry grain crops. Among them, the annual sown area of wheat is 36.5 million mu, with a total output of 14 million tons; the area of rice is 34.5 million mu with a total output of 14.5 million tons; and the area of corn is 1300. 10,000 mu, with a total output of 5 million tons; soybean area of 12.5 million mu, with a total output of 1.3 million tons. The vegetable area is 14.18 million mu, with a total output of 28.92 million tons. Abundant agricultural products resources not only meet the needs of the province, but also occupy a certain share in the domestic and foreign markets. Some specialty agricultural products are welcomed by consumers in the international market. Anhui is also a major animal husbandry province in the country. In 2017, the province's total output of meat, eggs and milk reached 5.744 million tons, of which 3.963 million tons of meat, 1.462 million tons of eggs, and 319,000 tons of milk; the output value was 128.57 billion yuan, accounting for 27.2% of the total agricultural output value. The total production of meat, eggs, and milk and the number of poultry and pigs for slaughter rank 11th, 6th and 11th in the country. There are 44 livestock and poultry breed resources in the whole province, and 5 breeds including Wanxi white goose, Huai pig, Anqing Liubai pig, Wannan black pig and Zhongfeng are included in the national protection list. The province has 21 large counties with national live pig transfers, a total of 652 ministerial and provincial-level livestock and poultry breeding standardization demonstrations have been established, and the proportion of large-scale livestock and poultry breeding has reached 57.4%. Anhui is also a major producer of freshwater aquatic products in China. The total area of inland waters such as ponds, lakes, reservoirs, rivers and rice fields ranks second in the country. In 2017, the total aquatic product output reached 2.4 million tons, ranking fourth in inland provinces. The province has 57 cities and counties with an annual output of more than 10,000 tons of aquatic products. In recent years, through the promotion of ecological and healthy breeding and adjustment and optimization of the species structure, the comprehensive production capacity of shrimp, crab, mandarin fish, turtle, loach, rice eel, and lake and reservoir organic fish has basically ranked among the top five in the country. The aquatic product farming area has expanded to 4.6 million mu, and the comprehensive planting and breeding area of rice and fishery in the province has reached 900000 mu.

According to the website of the Department of Agriculture of Anhui Province, the province's fertilizer use and pesticide use have achieved negative growth for three consecutive years; the fertilizer utilization rate and the pesticide utilization rate reached 37.6% and 39.6%, respectively. The province organized the implementation of the "zero growth" action of chemical fertilizer use. The province's chemical fertilizer use decreased from 3.414 million tons in 2014 to 2.987 million tons in 2019, an average annual decline of 2.6%, achieving five consecutive declines; average per mu (planting area) fertilization was reduced from 25.1 to 21.8 kg, and the fertilizer utilization rate of main crops increased from 34.4 to more than 39%. The use of pesticides in the province has decreased from a maximum of 118,000 tons in 2013 to 88,000 tons in 2019, with an average annual decrease of 4.8%, achieving six consecutive declines. The unit use (per hectare of sown area) has been reduced from 12.3 to 9.3 kg. The utilization rate of pesticides increased from 36.8% in 2015 to 41%, and the coverage rates of green prevention and control and unified prevention and governance increased to 38.2% and 44.4% respectively. Through the statistical information website, we checked the comprehensive economic rankings, per capita income, agricultural and animal husbandry production scales of the counties in Anhui Province (see the first 3 rows of Table 2), and selected 10 typical counties and cities to which they belonged to conduct research.

Materials and methods

Methodology

Selection of evaluation index system

First of all, we consulted the relevant information on the safety of edible agricultural products, and visited the supervisors of several agricultural markets near our unit, so as to have a preliminary understanding of the main problems existing in China's edible agricultural products and the general situation of food supervision in the market. Then, we paid a special visit to Zhou GH, Professor of School of Food Science and Technology of Nanjing Agricultural University and Academician of International Academy of Food Science and Technology (IAFoST); Professor Li JC, College of Agriculture, Anhui Agricultural University; Professor Gu HY, director of Institute of Rural Economy, Shanghai Jiaotong University; and Professor Kong XZ, School of Agriculture and Rural Development, Renmin University of China. We have listened carefully to their guiding opinions: The developed countries have done a good job in food safety, and the implementation standards are relatively high, which is worthy of our learning, but we should mainly consider China's national conditions. At present, China's agricultural production mode is still relatively traditional, and the application intensity of chemical fertilizers and pesticides is generally high. The evaluation of food safety should not only ensure people's health, but also combine with the overall level that China can achieve. The established index system mainly includes the food that has been tested by the state, and also conforms to the actual situation of the region. After repeated discussions and multiple rounds of screening, our research group finally selected the following 24 kinds of edible agricultural products with prominent harmful residues, which were classified into 6 categories, and established the evaluation index system shown in Table 1. In determining the weight of indicators, we invited Zhou GH and other four experts as special experts (see the "Determine the weight of each index" section), and our indicator system was also recognized by them.

Green vegetables include cabbage, celery and other vegetables with leaves as food materials. In addition to winter, green vegetables are easy to grow insects, usually with heavy pesticide application. Cucumber, towel gourd and tomato in addition to the intensity of pesticide application, there are also operators of illegal spraying ripening agent. Shuifa food includes dried agaric, dried tremella, and dried vegetables. Some operators in order to shoddy, using toxic drugs on the quality of very poor water hair food "make-up", so often it contains high formaldehyde. Pesticide residues and ripening agents are mainly detected in fruits, especially strawberries, bananas, apples and oranges. Pork mainly detected clenbuterol; poultry mainly detected excessive antibiotics. For poultry eggs, regulators mainly detect whether poultry have been injected with toxic colorants, and use cultured eggs to pass off as wild ones. Cattle and sheep mainly eat grass, generally not easy to get sick, rarely feed antibiotics, cattle and mutton rarely have problems, so they are not included. At present, there are many problems in crucian carp and silver carp. The main problems are that farmers overfeed antibiotics, and kerosene and copper sulfate are used to keep the fish alive for a long time in the process of transportation and marketing. *Monopterus albus* and *Misgurnus anguillicaudatus* were mainly tested whether they were fed with hormone. Bean sprout is mainly used to detect whether it has been sprayed with growth-promoting drugs, while tofu and dried bean are mainly used to detect toxic additives. Frozen meat and hairtail belong to cold chain food, mainly testing whether there is processed "zombie meat", or spray formaldehyde to keep fresh.

Determine the weight of each index

To determine the index weight, the common methods are "Delphi" method, "Entropy weight" method, and "AHP" method. Delphi method was initiated by Helm O and Darke N in 1940s, and further developed by Golden T and Rand C. The essence of Delphi law is to concentrate the knowledge and experience of experts. Then, this method has been widely used, such as Wagale and Singh 2019) applied adaptive neural fuzzy inference system and fuzzy comprehensive evaluation model to evaluate the social and economic impact of rural highway construction. Delphi method is used to determine the weight of each index. Main characteristics of Delphi method as the following: (1) each expert makes decisions

Table 1 Risk assessment index system of pesticide residues in edible agricultural products

Level I indicators and weights	Level II indicators	Indicator weight						
		AHP	Entropy weight (1)	Combined average (1)	Entropy weight (2)	Combined average (2)	Entropy weight (3)	Combined average (3)
B_1 Grain (0.262)	C_{11} Rice	0.3602	0.1531	0.2981	0.1205	0.2884	0.0372	0.2633
	C_{12} Noodle	0.3834	0.3488	0.3730	0.0862	0.2942	0.1773	0.3216
	C_{13} Corn	0.2564	0.4981	0.3289	0.7933	0.4174	0.7855	0.4151
B_2 Vegetables (0.184)	C_{21} Green vegetables	0.2131	0.2562	0.2260	0.0862	0.1752	0.0924	0.1771
	C_{22} Cucumber	0.1903	0.1773	0.1864	0.1973	0.1824	0.3051	0.2248
	C_{23}Tomatoes	0.2035	0.1072	0.1746	0.1331	0.2312	0.1301	0.1818
	C_{24} Towel gourd	0.1832	0.3187	0.2237	0.3599	0.2102	0.2112	0.1917
	C_{25} Shuifa food	0.2089	0.1404	0.1883	0.2235	0.201	0.2612	0.2246
B_3 Fruits (0.120)	C_{31} Strawberry	0.2819	0.5270	0.3554	*	*	*	*
	C_{32} Banana	0.2651	0.1424	0.2283	*	*	*	*
	C_{33}Apple	0.2079	0.1594	0.1934	*	*	*	*
	C_{34} Orange	0.2451	0.1712	0.2229	*	*	*	*
B_4 Meat, eggs (0.218)	C_{41} Pork	0.2101	0.0644	0.1664	0.1328	0.1869	0.0988	0.1767
	C_{42} Chicken	0.2210	0.0256	0.1624	0.1846	0.2101	0.2699	0.2357
	C_{43} Duck meat	0.2205	0.0100	0.1574	0.1821	0.2090	0.1333	0.1943
	C_{44}Poultry eggs	0.1603	0.1084	0.1447	0.2031	0.1731	0.1305	0.1514
	C_{45} Frozen meat	0.1881	0.7916	0.3691	0.2974	0.2209	0.3675	0.2419
B_5 Aquatic products (0.142)	C_{51} Crucian carp	0.2556	0.9726	0.4707	0.2793	0.2627	0.2412	0.2512
	C_{52} Silver carp	0.2712	0.0025	0.1906	0.4915	0.3372	0.4371	0.3210
	C_{53} Monopterus albus, loach	0.2086	0.0046	0.1474	0.1375	0.1874	0.2319	0.2156
	C_{54} Hairtail	0.2646	0.0203	0.1913	0.0917	0.2127	0.0898	0.2122
B_6 Bean products (0.074)	C_{61} Bean sprouts	0.4202	0.9974	0.5933	0.2453	0.3677	0.3296	0.3930
	C_{62} Bean curd	0.3602	0.0005	0.2523	0.4249	0.3796	0.3626	0.3609
	C_{63} Dried tofu	0.2196	0.0021	0.1544	0.3298	0.2527	0.3078	0.2461

Where Combined average(i) = 0.7 *AHP* + 0.3 *Entropy weight*(*i*) = 1, 2, 3

independently and is not influenced by other experts; (2) each expert directly gives weight to each evaluation index based on experience, without the help of mathematical model; (3) it does not need complex calculation to synthesize experts' opinions, and it directly calculates the average and variance of the results given by experts. And the comprehensive results are anonymously fed back to the experts, so that the experts can independently give each index weight again after thinking. Generally, it needs to repeat several rounds until the variance is very small. For the weight of level I indicators B_1, $B_2 \cdots B_6$, we use the "Delphi" method. We have set up a 7-member expert group, including 4 external experts (Zhou GH, Li JC, Gu HY and Kong XZ), 3 professors and doctors of our research group. Let each expert independently give the weight of indicators B_1, $B_2 \cdots B_6$, and then, the comprehensive results are fed back to each expert. A total of three rounds were repeated. The final results are shown in Table 1. The weight of level II indicators is relative to level I indicators. We first use Entropy weight method and AHP method, take the average value of the two, and then use mathematical software to calculate, with the results listed in Table 1.

Situation 1. The steps of weight calculation by entropy weight method

"Entropy" is a measure reflecting the disorder degree of system in information theory. Entropy can be used to judge the dispersion degree of an index. In many comprehensive evaluation problems, people use the entropy value of the index to determine the weight (Fan et al. 2012). For example, we find the weight of level II indicators C_{h1}, $C_{h2} \cdots C_{hn}$, with respect to level I indicator B_h, and denote it as $B_h(C_h) = \left(w_i^h, w_2^h, \cdots w_n^h\right)$ $h = 1, 2, \cdots 6$. Suppose that the standardized index value of index C_{hi} $(i = 1, 2, \cdots, n)$ in the j-th participating unit is $\overline{C}_{hi}(j)(j = 1, 2, \cdots, m)$

(i) Unitization of vector $\left(\overline{C}_{hi}, (1), \overline{C}_{hi}, (2), \cdots \overline{C}_{hi}, (m)\right)$ That is to calculate the P_{ij} of $\overline{C}_{hi}, (j)$'s specific gravity in the C_{hi}

$$P_{ij} = C_{hi}, (j) / \sum_{j=1}^{m} C_{hi}, (j) \quad (1)$$

(ii) Calculate the entropy e_i, of the indicator C_{hi}

$$e_i, = -k \sum_{j=1}^{m} \ln P_{ij}, k = 1/\ln m, e_i \epsilon [0, 1] \quad (2)$$

(iii) Calculate difference coefficient g_i of indicator C_{h1}

$$g_i = 1 - e_i, \quad (3)$$

The greater the difference between indicator values $\overline{C}_{hi}, (1)$ $, \overline{C}_{hi}, (2), \cdots \overline{C}_{hi}, (m)$ the smaller the entropy e_i of indicator C_{hi} and the greater the difference coefficient of indicator C_{hi} is.

(iv) The weights of each indicator can be obtained by normalizing the coefficient of difference:

$$w_i^h = g_i / \sum_{i=1}^{n} g_i (i = 1, 2, \cdots, n) \quad (4)$$

Because entropy calculation needs to use the specific distribution of indicators, Entropy weight (1), Entropy weight (2) and Entropy weight (3) in Table 1 are calculated according to the data in Table 3, Table 5 and Table 7 respectively.

Situation 2. The steps of AHP method for weight calculation

Analytic Hierarchy Process (AHP) method was proposed by Professor Saaty T of the University of Pittsburgh, an American operations researcher, in the early 1970s. It is used to determine the weight of multiple the lower level indicators on the upper level indicators (Riccardo et al. 2013). It does not need to use the specific statistical data of each indicator, but is completely made according to the judgment made by experts independently based on their experience, and then determine the weight of each index through a series of calculations. Using the seven-member expert group established by us, the AHP weights of all level II indicators relative to level I indicators are calculated according to the following methods. The results are shown in the AHP in Table 3. In general, let's find the weight of level II indicators C_{h1}, C_{h2}, $\cdots$, C_{hn} with respect to level I indicator B_h, and record it as $B_h(C_h) = \left(w_1^h, w_2^h, \cdots, w_n^h\right)$ $(h = 1, 2, 3, 4)$.

(i) Ask each expert in the expert group to compare the importance of each pair of indicators C_{1i}, $C_{1j}(i, j = 1, 2, \cdots, n)$, and construct a positive reciprocal judgment matrix. Let the matrix constructed by the k-th expert be as follows:

$$R(k) = \begin{bmatrix} u_{11}^{(k)} & u_{12}^{(k)} & \cdots & u_{1n}^{(k)} \\ u_{21}^{(k)} & u_{22}^{(k)} & \cdots & u_{2n}^{(k)} \\ \cdots & \cdots & \cdots & \cdots \\ u_{n1}^{(k)} & u_{n2}^{(k)} & \cdots & u_{nn}^{(k)} \end{bmatrix}, k = 1, 2, \cdots, 7.$$

where $u_{ij}^{(k)}$ indicates that the k-th expert considers the degree of importance of indicator C_{hi} relative to indicator C_{hj}, their values are taken from $\frac{1}{9}, \frac{1}{8}, \cdots, \frac{1}{2}, 1, 2, \cdots, 9$. Obviously, $u_{ij}^{(k)} = 1/u_{ji}^{(k)}, u_{ii}^{(k)} = 1$. Noting $\overline{u}_{ij} = \sqrt[7]{\prod_{k=1}^{7} u_{ij}^{(k)}}$ $(i, j = 1, 2, \cdots, n)$, it is easy to prove that

$$\overline{R} = \begin{bmatrix} \overline{u}_{11}\overline{u}_{12}\cdots\overline{u}_{1n} \\ \overline{u}_{21}\overline{u}_{22}\cdots\overline{u}_{2n} \\ \cdots\cdots\cdots\cdots \\ \overline{u}_{n1}\overline{u}_{n2}\cdots\overline{u}_{nn} \end{bmatrix},$$

is still a positive reciprocal matrix, and satisfies $\overline{u}_{ii} = 1, \overline{u}_{ij} = 1/\overline{u}_{ji} > 0$.

(ii) Check the consistency of the positive reciprocal matrix $\overline{R}$. We calculate the maximum eigenvalue λ_n of the $\overline{R}$ and the value of the indicator $CR = CI/RI$, where $CI = (\lambda_n - n)/(n - 1)$. There is a fixed corresponding relationship between the value of RI and the order of $\overline{R}$, which is given in Table 2 (Riccardo et al. 2013).

When $CR < 0.1$, it is considered satisfactory (otherwise reconstruct $R(k)$ and R).

(iii) The characteristic vector $\overline{a} = (\overline{a}_1, \overline{a}_2, \cdots, \overline{a}_n)$ of matrix $\overline{R}$ corresponding to the λ_n is calculated with a simple method, where $\overline{a}_i = \sqrt[n]{\prod_{j=1}^{n} \overline{u}_{ij}}, i = 1, 2, \cdots, n$. By uniting the vector $\overline{a}$, we can get $B_h(C_h) = \left(w_1^h, w_2^h, \cdots, w_n^h\right)$, where $w_i^h = \overline{a}_i / \sum_{i=1}^{n} \overline{a}_i$.

Table 2 The corresponding relationship between the value of RI and the order of $\overline{R}$

n	3	4	5	6	7	8	9
RI	0.58	0.90	1.12	1.24	1.32	10.4	1.45

For example, we find the weight of the index $C_{21}, C_{22}, \cdots, C_{25}$ for the index B_2. We synthesize the judgment matrix given by seven experts and get

$$\overline{R} = \begin{bmatrix} 1 & 1.1198 & 1.0472 & 1.1632 & 1.0201 \\ 0.8930 & 1 & 0.9351 & 1.3876 & 0.9110 \\ 0.9550 & 1.0694 & 1 & 1.1108 & 0.9742 \\ 0.8597 & 0.9627 & 0.9002 & 1 & 0.8770 \\ 0.9829 & 1.0977 & 1.0265 & 1.1403 & 1 \end{bmatrix}, \lambda_5$$

$$= 5.06682, CR = 0.01492.$$

Because the $\overline{R}$ is more satisfactory, we get

$$B_2(C_2) = \left(w_1^2, w_2^2, \cdots, w_5^2\right) = (0.2131, 0.1903, 0.2035, 0.1832, 0.2089).$$

The characteristic of entropy weight method is that it makes full use of the entropy of index to determine the weight, which seems to be more objective. In fact, this method also has limitations, no matter whether the index is important or not, as long as the index value difference is large, the entropy is small, and the corresponding weight is large, which is mainly suitable for evaluating the differences between different evaluation units. For example, in the five level II indicators of the level I indicatorB_5, for indicator C_{51}, the Entropy weight (1) calculated according to the data in Table 3 is 0.9726, and the Entropy weight (2) calculated according to the data in Table 5 is 0.2793. For indicator C_{52}, we calculated Entropy weight (1) as 0.0025 and Entropy weight (2) as 0.4915. This is obviously not very reasonable (see Table 1).

AHP method is only based on the importance of each indicator, which is mainly suitable for evaluating the degree of reaching the standard of the participating units. The main basis of this evaluation should be the importance of all kinds of edible agricultural products in the total food consumption, taking into account the differences in the quality of edible agricultural products in different cities and counties. So the weight of the level II indicator is determined by the combination of entropy weight method and AHP method. And in combination weight, entropy weight only accounts for 0.3, while AHP weight accounts for 0.7

Two-level comprehensive fuzzy evaluation method

Fuzzy set theory was put forward by American automatic control expert Professor Zadeh L in 1965 to express the uncertainty of things. In recent decades, the operation of fuzzy sets, the theory and application of fuzzy comprehensive evaluation have developed rapidly. For example, Wagale et al. (2019) applied fuzzy comprehensive evaluation model to evaluate the social and economic impact of rural highway construction. If we divide the degree of harmful substances in edible agricultural food into several grades, the boundary of these grades must be fuzzy, and it is suitable to use the two-level fuzzy comprehensive evaluation model to evaluate them. Generally, the total indicator $\overline{\overline{B}}$ of evaluation object involves m level I indicators $B_1, B_2, \cdots, B_m$, and their weight vector is $a = (w_1, w_2, \cdots, w_m)$. Indicator $B_i(i = 1, 2, \cdots, m)$ includes m_i level II indicators $C_{i1}, C_{i2}, \cdots, C_{im_i}$, and their weight vector about indicator B_i is: $b_i = (v_{i1}, v_{i2}, \cdots, v_{in_i})$. The quality of all indicators was divided into n grades: $A_1, A_2, \cdots, A_n$. The membership function of indicator $C_{ij}(i = 1, 2, \cdots, m, j = 1, 2, \cdots, m_i)$ is:

$$\widetilde{C}_{ij} \to r_{ij1}/A_1 + r_{ij2}/A_2 + \cdots + r_{ijn}/A_n = \left(r_{ij1}, r_{ij2}, \cdots, r_{ijn}\right).$$

$$\text{Let} \quad R_i = \begin{bmatrix} r_{i11} & r_{i12} & \cdots & r_{i1n} \\ r_{i21} & r_{i22} & \cdots & r_{i2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{im_i1} & r_{im_i2} & \cdots & r_{im_in} \end{bmatrix}, (i = 1, 2, \cdots, m) \quad (5)$$

be the fuzzy evaluation matrix of indicator B_i.

First level evaluation: The fuzzy evaluation results of indicator $B_i(i = 1, 2, \cdots, m)$ were as follows

$$\widetilde{r}_i = b_i \circ R_i = (v_{i1}, v_{i2}, \cdots, v_{im_i}) \circ \begin{bmatrix} r_{i11} & r_{i12} & \cdots & r_{i1n} \\ r_{i21} & r_{i22} & \cdots & r_{i2n} \\ \cdots & \cdots & \cdots & \cdots \\ r_{im_i1} & r_{im_i2} & \cdots & r_{im_in} \end{bmatrix} = (s_{i1}, s_{i2}, \cdots, s_{in}). \quad (6)$$

where

$$s_{ik} = (v_{i1}, v_{i2}, \cdots, v_{im_i}) \circ \begin{bmatrix} r_{i1k} \\ r_{i2k} \\ \vdots \\ r_{im_ik} \end{bmatrix} = (v_{i1} \wedge r_{i1k}) \vee (v_{i2} \wedge r_{i2k}) \vee \cdots \vee (v_{im_i} \wedge r_{im_ik}), k = 1, 2, \cdots n.$$

The "∧" is the symbol of multiplication of fuzzy numbers, which means to take the minimum value; the "∨" is the sign of fuzzy number addition, which means to take the maximum value.

$$\text{Let} \quad R = \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n} \\ s_{21} & s_{21} & \cdots & s_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ s_{m1} & s_{m2} & \cdots & s_{mn} \end{bmatrix}, \quad (7)$$

be total fuzzy evaluation matrix. If the maximum value in the ith row of the matrix R first appears in the j-th column, then the quality of the factor B_i is evaluated as A_j (try to give good comments).

Table 3 Food pesticide residue compliance in some farmers' markets in 10 cities (%)

	Hefei	Huaibei	Fuyang	Tongling	Wuhu	Ma'anshan	Anqing	Chuzhou	Lu'an	Xuancheng
C_{11}	98.81	98.05	98.65	97.42	97.91	97.83	98.21	98.63	98.71	98.72
C_{12}	96.21	96.90	96.23.	97.02	96.26	97.10	95.68	95.21	95.42	95.25
C_{13}	83.61	86.12	87.72	84.03	84.12	83.37	85.30	85.27	84.30	85.02
C_{21}	82.14	83.01	81.25	82.34	82.15	84.03	82.05	83.14	83.07	82.51
C_{22}	87.51	86.30	87.25	86.03	86.21	85.23	86.24	87.10	86.31	86.24
C_{23}	85.12	85.13	84.41	85.07	84.26	84.42	84.36	85.07	84.21	83.62
C_{24}	86.31	86.43	85.47	85.30	87.01	87.12	84.26	86.23	85.37	86.61
C_{25}	85.40	85.12	86.03	84.68	85.62	84.16	84.23	85.06	85.10	85.34
C_{31}	96.03	96.24	95.83	96.61	96.45	95.36	96.14	96.23	95.72	95.40
C_{32}	97.24	97.25	96.83	96.57	97.02	97.25	96.94	97.02	97.21	96.97
C_{33}	98.63	98.27	97.98	98.31	98.52	98.41	98.43	98.05	97.98	98.52
C_{34}	98.20	98.12	98.31	97.86	97.59	98.06	98.13	97.84	97.60	97.95
C_{41}	98.62	98.81	98.54	98.20	98.32	98.16	98.42	98.26	98.20	98.35
C_{42}	98.01	98.12	98.43	98.10	98.31	98.22	98.05	98.12	98.31	98.14
C_{43}	98.12	98.10	98.22	98.13	98.12	98.01	98.23	98.21	98.03	98.02
C_{44}	98.85	98.61	98.15	98.13	98.20	98.11	98.14	98.02	98.10	98.02
C_{45}	89.92	90.21	90.35	89.84	88.50	88.97	88.74	89.02	89.21	90.12
C_{51}	98.71	98.35	98.24	98.63	98.20	98.01	98.15	98.31	87.63	88.25
C_{52}	98.65	98.23	98.21	98.22	97.90	98.11	98.30	98.07	98.15	97.82
C_{53}	97.13	98.03	98.10	97.92	98.03	97.95	98.14	97.52	97.83	97.91
C_{54}	89.57	89.63	88.67	89.01	87.62	88.41	89.02	89.23	88.67	88.62
C_{61}	98.63	98.51	98.20	98.41	88.16	89.02	89.06	88.63	88.74	89.12
C_{62}	98.21	98.16	98.03	98.22	97.92	98.24	98.05	98.13	98.14	98.30
C_{63}	98.61	98.42	98.23	98.31	98.11	98.24	98.80	98.12	98.05	98.14

Second level evaluation: The fuzzy evaluation result of the total indicator $\overline{\overline{B}}$ of the evaluation object is

$$a\circ R = (w_1, w_2, \cdots, w_m)\circ \begin{bmatrix} s_{11} & s_{12} & \cdots & s_{1n} \\ s_{21} & s_{21} & \cdots & s_{2n} \\ \cdots & \cdots & \cdots & \cdots \\ s_{m1} & s_{m2} & \cdots & s_{mn} \end{bmatrix}$$
$$= (t_1, t_2, \cdots, t_n). \quad (8)$$

If the maximum component of the vector $(t_1, t_2, \cdots, t_n)$ first appears in the j-th column, the total evaluation level of the evaluation object is determined as A_j. In addition, we calculate

$$\widetilde{S}_i = \left(s_{i1} + s_{i2} + \cdots + s_{ij}\right)/\left(s_{i1} + s_{i2} + \cdots + s_{\boldsymbol{in}}\right), \widetilde{S}_T$$
$$= \left(t_1 + t_2 + \cdots + t_j\right)/\left(t_1 + t_2 + \cdots + t_n\right). \quad (9)$$

$\widetilde{S}_i$ and $\widetilde{S}_T$ respectively indicate that the quality of indicator $B_i(i = 1, 2, \cdots, 6)$ and comprehensive indicator $\overline{\overline{B}}$ is considered not lower than the total membership of A_j. That is to say, among all the respondents, the proportion of those who think that the grade of the evaluation object is not lower than A_j (see the "Investigation on the production and consumption of edible agricultural products in 10 counties" section for specific examples).

Damage-abatement production function with pesticide as a factor

The output of agricultural products mainly depends on the input of fertilizer (expressed by x_1) and labor (including comprehensive labor input, expressed by x_2). Other rigid factors such as seed, irrigation and machine tillage do not need to be included in the model. Therefore, yield is generally reflected by *C-D* production function $y = ax_1^{\beta_1}x_2^{\beta_2}$. The pursuit of economic benefits is the fundamental purpose of farmers engaged in agricultural production. Pesticides cannot directly promote the growth of crops and produce value, but can indirectly produce value by reducing diseases, insects and weeds and avoiding the reduction of crop production. The behavior of farmers applying pesticides is a kind of production investment. The basic starting point is to do their best and make use of the scientific and technological conditions at that time, and strive to recover the losses of agricultural products caused by diseases, insects and weeds to the greatest extent with the minimum pesticide investment. Hall and Norgaard (1973) and Talpaz and Borosh (1974) creatively proposed that pesticide is also a factor of production, and based on this, Damage-abatement production function model was constructed. A three-dimensional yield description system including fertilizer, labor and pesticide was formed. In 1995, Fox and Weersink made a summary and comparison of the specific forms of Damage-abatement production function.

According to the research results of Shen (2011), herbicides mainly pollute the land, destroy the biota in the land, and affect the growth of crops. If applied correctly, especially in the early stage of crop growth, the impact on human and livestock is very small. Therefore, this paper mainly considers insecticides and sets the maximum degree of crop yield reduction caused by insect disaster as ($i = 1, 2, \cdots, 13$) If the pesticide input per mu of crops is T, the pest damage can be reduced by $C(T)$, with $dC(T)/dT >$ 0, and when $T = 0$, $C(T) = 0$. Therefore, when the pesticide cost of pest control is input per mu, the actual yield of each mu of crop becomes

$$y = ax_1^{\beta_1}x_2^{\beta_2}(1-\delta) + \delta ax_1^{\beta_1}x_2^{\beta_2}C(T). \tag{10}$$

This formula is called Damage-abatement production function considering pesticide input. Scholars have different opinions on the specific form of $C(T)$, such as Parteo form, let$C(T) = 1 - (k/T)^2$; Exponential form, let $C(T) = 1 - exp(-mT)$; Weibull form, let$C(T) = 1 - exp(-T^m)$.

Collection and arrangement of data

From July to August 2020, using the summer vacation of students to return home and combining social practice activities, we arranged 20 students living in Anhui and neighboring provinces, and conducted 8 weeks of investigation activities in 10 cities and 10 counties in Anhui Province. They were divided into five groups, each with a master's degree student in charge of the investigation of two cities and two counties. The overall framework of our research is shown in Fig. 1.

Investigation on the quality of edible agricultural products consumed in 10 cities

In Hefei and other 10 cities in Anhui Province, we investigated the "Smart Agricultural Trade Data Center" of 40 farmers' markets, 20 individual edible agricultural products stores, and student canteens of 40 schools. At present, only 14 pesticide residues were detected, including pesticide residues in vegetables and fruits. Meat essence "ractopamine" in meat. Malachite green in aquatic products. In other classes, formaldehyde and so on, and the implementation standard is relatively low. For example, the comprehensive inhibition rate[1] of pesticide residues is less than 50%, and ractopamine is less than 0.5hhp, it is considered qualified. After setting the detection type and the upper limit of pesticide residues, the rapid detection equipment only shows negative or positive, and does not show the specific degree of compliance. We checked the spot check records of each "Smart Agricultural Trade Data Center" in the last month, including the stalls, food names and index values of the items sampled every day. We can see that almost every market has some stalls selling ecological food, such as "running pork" (free range pigs without hormone), wild fish. Consumers say the quality is really good, but the price is at least 10% higher than other stalls, and the business is slightly better than other stalls. In order to reduce the random volatility of the sample data, for each city's 24 survey indicators, we counted the average compliance degree of the four "Smart Agricultural Trade Data Center" in each city in the last 30 days (see Table 3). Method: For example, for indicator C_{11} first count the total number of times that indicator C_{11} is inspected and the total number of times that indicator C_{11} reaches the standard within 30 days in each market, calculate the average rate of reaching the standard within 30 days in each market, and then calculate the average rate $\overline{C}_{11}$ of reaching the standard in four markets.

Using Combined average (1) in Table 1, we calculate the average exceeding standard rate of 6 kinds of food pesticide residues in 10 urban farmers' markets, and finally calculate the comprehensive exceeding standard rate of 6 kinds of food pesticide residues (denoted by $\overline{\overline{B}}$), as shown in Table 4.

At the same time, we investigated the food pesticide residues in four school canteens in each city. The government has strict supervision on school canteens, and the food and drug regulatory authorities in the jurisdiction usually inspect the school's food materials once a week. The unqualified food materials shall be destroyed immediately, and the Contractor shall explain the source and write down the rectification plan. Most school canteens have fixed food suppliers, and the phenomenon of excessive pesticide residues is lower than that in the market. Large-scale school management departments use self-purchased rapid detector to spot check the food materials of the canteen from time to time. We have checked the inspection records of the supervision department kept by each school in recent 1 year. For 20 survey indicators of school canteens (canteens do not operate fruits), we have counted the average compliance rate of four schools in each city in recent three months (see Table 5). The method is the same as that of the market average rate.

[1] Inhibition rate: under certain conditions, organophosphorus and carbamate pesticides can inhibit the normal function of cholinesterase, and the inhibition rate is positively correlated with the concentration of pesticides. By calculating the inhibition rate, we can judge whether there is a high dose of this kind of pesticide in the sample.

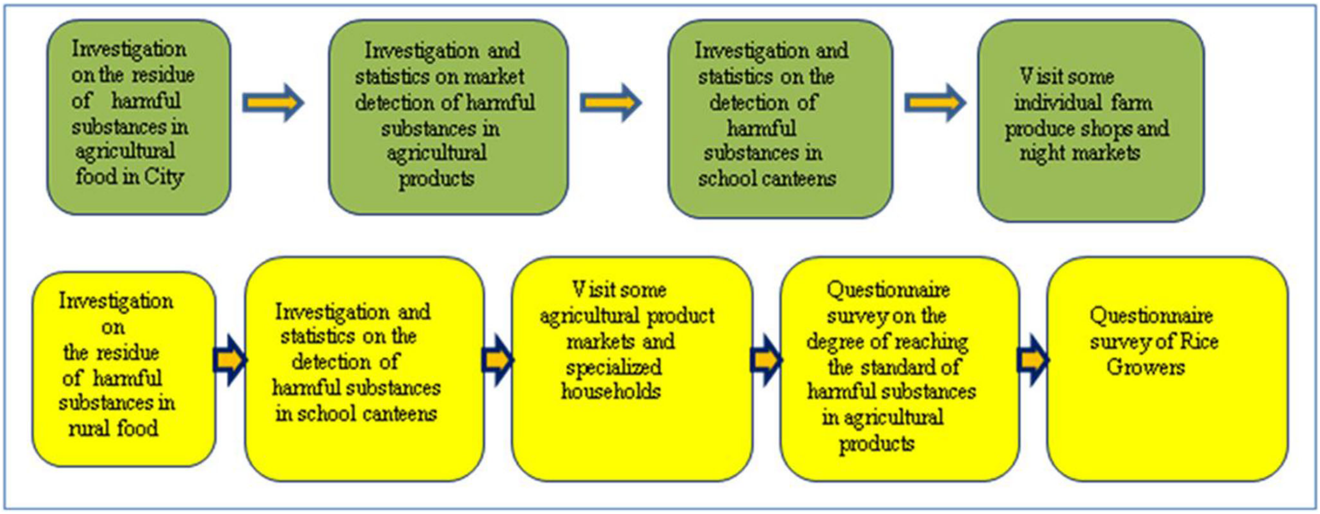


Fig. 1 Research framework on pollution control of edible agricultural products in Anhui Province

Using Combined average (2) in Table 1, we calculated the average exceeding standard rate of 5 categories of food pesticide residues in school canteens of 10 cities, and finally calculated the comprehensive exceeding standard rate of 5 categories of food pesticide residues, as shown in Table 6. When calculating the comprehensive exceeding standard rate, because the school canteen does not sell fruit, the weight of fruit 0.12 in Table 1 is allocated to the other five categories in proportion, and the weight of five categories of food is adjusted as follows: 0.2977, 0.2091, 0.2477, 0.1614, 0.0841.

We also visited some individual farmers' food stores in each city, and the food regulatory authorities in the jurisdiction supervised these stores. The shopkeeper showed us the qualification records of some food spot checks, including the date and variety of spot checks. Sampling time is basically irregular, the interval is short 1 week, the longest 2 months. It is estimated that the owner will not introduce the unqualified situation of sampling inspection, so we do not count the food quality of individual stores. We also see that in the evening, there are some stalls on both sides of the streets near many residential areas, including those selling fruits, corn, vegetables and other agricultural products. The agricultural residues of these stalls are basically in a laissez faire state. However, the scale of agricultural products sold in individual stores and night markets is not large, and we estimate that it will not exceed 10% of the total amount of edible agricultural products consumed in cities, and individual stores are under the semi monitoring of the government. Therefore, it can be asserted that more than 95% of the edible agricultural products in cities are under government monitoring.

Investigation on the production and consumption of edible agricultural products in 10 counties

We chose another sample county from each sample city to conduct field research on the control of edible agricultural products in these counties. Distribution of sample counties: Suixi County and Linquan County in Huaibei plain; Zongyang County along the river plain, Wuwei County and Dangtu County; Feixi of Jianghuai hills, Taihu Lake and Fengyang County; Jinzhai County in Dabie Mountain Area in West Anhui Province and Jingxian County in southern Anhui Province. Suixi County has 11 towns, Linquan county has 23 towns, Zongyang County has 19 towns, no county has 21 towns, Dangtu County has 25 towns, Feixi County has 13 towns, Taihu County has 15 towns, Fengyang County has 17

Table 4 Classification and summary of food pesticide residue compliance rate in 10 cities (%)

	Hefei	Huaibei	Fuyang	Tongling	Wuhu	Ma'anshan	Anqing	Chuzhou	Lu'an	Xuancheng
B_1	92.862	93.697	94.153	92.867	92.759	92.802	93.020	92.960	92.743	92.920
B_2	85.126	85.073	84.683	84.525	84.934	84.954	84.057	85.185	84.687	84.767
B_3	97.293	97.282	97.027	97.208	97.235	96.983	97.209	97.121	96.916	96.930
B_4	98.957	95.383	95.392	95.077	94.645	94.747	94.717	94.784	94.858	95.179
B_5	96.717	96.612	96.383	96.607	96.094	96.184	96.431	96.412	91.338	91.569
B_6	98.521	98.408	98.162	98.347	92.159	92.770	92.832	92.492	92.549	92.829
$\overline{\overline{B}}$	94.265	93.671	93.639	93.271	92.697	92.695	92.714	92.882	92.009	92.195

Table 5 Average compliance rate of 20 indicators of school canteens in 10 cities (%)

	Hefei	Huaibei	Fuyang	Tongling	Wuhu	Ma'anshan	Anqing	Chuzhou	Lu'an	Xuancheng
C_{11}	99.02	98.78	98.51	98.12	98.23	98.21	98.02	98.45	98.26	98.71
C_{12}	97.52	97.54	97.23.	97.56	97.62	97.53	98.01	97.92	97.31	97.46
C_{13}	97.54	97.92	98.03	96.38	97.29	95.13	96.43	97.62	97.30	96.85
C_{21}	84.21	84.71	85.14	84.52	84.71	85.12	84.50	85.03	85.42	84.34
C_{22}	88.61	88.25	87.96	87.47	87.43	86.24	87.26	87.98	87.62	88.12
C_{23}	85.12	85.13	84.41	85.07	84.26	84.42	84.36	85.07	84.21	83.62
C_{24}	86.31	86.43	85.47	85.30	87.01	87.12	84.26	86.23	85.37	86.61
C_{25}	87.53	87.21	88.04	87.23	87.12	85.62	86.04	87.12	87.31	87.13
C_{41}	98.21	98.65	98.02	98.53	98.14	98.23	98.05	97.98	98.02	97.90
C_{42}	97.56	97.18	98.03	98.21	98.05	98.12	98.06	97.89	97.90	98.20
C_{43}	98.08	97.25	98.43	98.01	98.11	97.95	97.62	98.12	97.91	97.86
C_{44}	99.00	98.91	98.36	98.65	98.71	98.23	98.24	98.32	98.14	97.95
C_{45}	96.41	97.12	97.31	96.82	96.13	96.51	96.33	97.10	97.24	97.26
C_{51}	97.40	97.21	97.04	96.85	96.43	97.20	96.35	97.85	97.52	97.41
C_{52}	96.62	96.38	97.05	97.21	96.27	98.52	96.43	96.81	97.13	96.52
C_{53}	95.21	95.20	94.82	95.31	94.74	94.51	95.01	95.21	94.78	94.63
C_{54}	97.05	97.42	96.75	96.81	97.13	96.85	96.92	97.03	97.12	97.01
C_{61}	98.26	98.21	98.13	98.22	98.10	97.91	98.05	98.11	98.23	97.86
C_{62}	98.41	98.31	98.84	98.15	98.07	98.45	98.41	97.92	98.00	98.22
C_{63}	98.23	98.32	98.21	98.24	98.24	98.12	98.22	97.91	97.95	97.65

towns, Jinzhai County has 28 towns, Jing County has 30 towns. Among them, Feixi, Wuwei, Dangtu and Suixi are the first, fifth, sixth and tenth counties in Anhui Province; Taihu, Jing and Jinzhai are all in the bottom 10. We visited the Agricultural and Rural Bureau of the sample county to understand the proportion, type and organization form of the characteristic planting and breeding, professional cooperative production in the sample county. Each county visited 8-10 villages and towns, visited the township agricultural technology station, understood the local farmers' acceptance of technical guidance, and visited some ecological production bases. We focus on the investigation of four middle school canteens in each county, including a county middle school. Only the mountainous primary schools with a very scattered population, some students have a meal in the canteen at noon, and generally there is no student canteen in rural primary schools. Kindergartens are concentrated in the county and rural towns, and all kindergartens have canteens. The government and school leaders are very serious about the management of student canteens, and dare not be careless. Some large-scale schools often carry out self-examination. The food inspection of student canteens is carried out by the county Drug and Food Supervision Bureau, but the rural schools are scattered, junior middle schools only check once every two months, senior middle schools and kindergartens check once every month. We counted the inspection records of four school canteens in the last year, first calculated the compliance rate of 20 survey indicators of each school, and then calculated the average compliance rate of four schools (see Table 7).

Table 6 Classification and summary of average standard rate of 20 indicators in canteen of 10 cities (%)

	Hefei	Huaibei	Fuyang	Tongling	Wuhu	Ma'anshan	Anqing	Chuzhou	Lu'an	Xuancheng
B_1	96.485	98.056	97.933	97.229	97.658	96.724	97.353	97.948	97.580	97.566
B_2	87.167	87.131	85.282	85.000	85.127	84.670	84.361	84.987	85.039	85.006
B_4	97.785	97.756	98.010	97.997	97.770	97.768	97.615	97.855	97.820	97.822
B_5	96.652	96.598	96.566	96.674	96.208	97.067	96.247	96.830	95.441	96.504
B_6	98.309	98.276	98.420	98.199	98.124	98.168	98.230	97.987	98.072	97.944
$\overline{\overline{B}}$	95.040	95.482	95.128	94.856	94.872	94.480	94.598	95.039	94.725	93.896

Using the Combined average (3) in Table 1, we calculate the average exceeding standard rate of five categories of food pesticide residues in school canteens in 10 cities, and finally calculate the comprehensive exceeding standard rate of five categories of food pesticide residues, as shown in Table 8.

There is no pesticide residue detection system for the county and rural markets, but there is a supervision system for meat products. The centralized slaughtering system for live pigs was implemented on February 18, 1998, and the centralized slaughtering system for all livestock and poultry was implemented on October 15, 2015. The designated slaughterhouse is responsible for the comprehensive health test of the livestock and poultry sent to the factory, and random sampling test of whether the livestock and poultry are fed antibiotics and clenbuterol hormone beyond the limit, the sampling rate shall not be less than 1%. All livestock and poultry meat sold by merchants must hold the quarantine certificate issued by the designated slaughterhouse. In each county, we also visited three professional livestock farm. The government has higher subsidies for large-scale breeding. However, the purchase (self processed) and use of each kind of feed need a detailed journal. The complete name and manufacturer of the additive must be indicated. The drug and food regulatory authorities under their jurisdiction conduct random checks on feed ingredients and blood of breeding animals from time to time, and pursue responsibility for the problems found out and impose heavy penalties. Therefore, the vast majority of meat products sold in rural markets should be under the supervision of the government.

In order to grasp more about the agricultural residues of rural edible agricultural products, we divide the level of harmful substances exceeding the standard in the edible agricultural products into the following: A_1 does not exceed the standard, A_2 slightly exceeds the standard, A_3 obviously exceeds the standard, A_4 seriously exceeds the standard. The boundaries of these levels are fuzzy. We sent out 100 questionnaires in the urban farmers' markets of each county. There are 24 survey indicators in the questionnaire, and each indicator is attached with 5 options of A_1, A_2, A_3, A_4, A_5. The respondents are required to choose one for each indicator. The effective questionnaires collected in 10 counties were at least 81 and at most 96. The proportion of each grade of each index is calculated by county, and the fuzzy membership relationship of 24 indexes in each county is obtained. For example, in the 87 valid questionnaires collected in Feixi County, the statistical results include $\widetilde{C}_{11} \rightarrow \left(\frac{18}{87}, \frac{28}{87}, \frac{17}{87}, \frac{14}{87}, \frac{10}{87}\right) = (0.2069, 0.3218, 0.1954, 0.1609, 0.1150)$. From (5), we get the fuzzy evaluation matrix of 6 level I indicators in Feixi County, as shown in Table 9.

Using (6) and AHP weight of the level II indicators in Table 1, we get the first level evaluation results of 6 level I indicators in Feixi County.

Table 7 Average compliance rate of 20 indicators of school canteens in 10 counties (%)

	Feixi	Wuwei	Dangtu	Suixi	Zongyang	Fengyang	Linquan	Taihu	Jinzhai	Jingxian
C_{11}	98.22	98.53	98.15	98.11	98.23	98.16	98.06	98.35	98.03	98.42
C_{12}	98.14	97.06	97.03	97.34	97.45	97.27	97.28	97.84	97.14	97.33
C_{13}	97.34	96.91	95.61	95.43	96.82	95.91	95.15	96.82	96.53	96.17
C_{21}	84.35	84.62	84.86	85.21	84.83	85.06	85.50	85.10	84.26	84.13
C_{22}	88.52	88.31	87.64	87.33	87.21	86.40	85.94	86.31	86.92	87.23
C_{23}	85.22	85.08	84.32	85.21	84.03	84.25	84.23	85.17	84.30	83.92
C_{24}	86.32	86.23	85.35	85.08	86.92	86.75	85.20	86.31	85.42	86.57
C_{25}	87.41	87.25	87.91	87.24	86.74	85.23	86.04	87.12	87.31	87.13
C_{41}	98.21	98.65	98.02	98.53	98.14	98.23	98.05	97.98	98.02	97.90
C_{42}	97.56	97.18	98.03	98.21	98.05	98.12	97.52	97.35	97.14	97.84
C_{43}	98.00	97.12	98.05	97.81	97.63	97.56	97.49	97.96	97.84	97.72
C_{44}	98.64	98.52	98.25	98.42	98.53	97.87	97.96	98.12	98.10	97.92
C_{45}	96.33	97.04	97.18	96.54	96.05	96.32	96.11	96.93	97.21	97.14
C_{51}	97.31	97.12	96.85	96.96	96.23	97.05	96.32	97.25	97.14	97.21
C_{52}	96.06	96.28	96.82	97.10	96.12	97.69	96.23	96.72	96.85	96.49
C_{53}	95.11	95.03	94.71	95.17	94.42	94.38	94.29	95.12	94.57	94.32
C_{54}	97.12	97.21	96.43	96.75	96.82	96.75	96.86	97.05	97.08	96.82
C_{61}	98.20	98.11	97.95	98.12	97.85	97.68	97.84	97.81	98.12	97.45
C_{62}	98.31	98.12	98.65	98.09	98.04	98.32	98.33	97.90	97.85	97.94
C_{63}	98.21	98.14	98.17	98.20	98.15	98.04	98.21	97.84	97.86	97.52

Table 8 Classification and summary of average standard rate of 20 indicators in canteen of 10 counties (%)

	Feixi	Wuwei	Dangtu	Suixi	Zongyang	Fengyang	Linquan	Taihu	Jinzhai	Jingxian
B_1	97.829	97.385	96.736	96.750	97.394	96.940	96.601	97.551	97.121	97.136
B_2	86.511	86.433	86.166	86.118	86.049	86.071	85.432	86.070	85.773	85.930
B_5	97.626	97.597	97.860	97.817	97.573	97.557	97.333	97.595	97.594	97.670
B_5	96.423	96.448	96.319	96.604	95.959	96.645	95.997	96.607	96.509	96.302
B_6	98.242	98.121	98.257	98.129	97.992	97.800	98.108	97.850	97.959	97.644
$\overline{\overline{B}}$	95.220	95.058	94.865	94.884	94.885	94.845	94.476	95.034	94.837	94.833

$$\widetilde{r}_1 = (0.3602, 0.3834, 0.2564)\circ R_1 = (0.2069, 0.3218, 0.2564, 0.2514, 0.1779),$$
$$\widetilde{r}_2 = (0.2131, 0.1903, 0.2035, 0.1832, 0.2089)\circ R_2 = (0.1452, 0.2131, 0.2131, 0.2131, 0.2131),$$
$$\widetilde{r}_3 = (0.2819, 0.2651, 0.2079, 0.2451)\circ R_3 = (0.1874, 0.2257, 0.2819, 0.2431, 0.2302),$$
$$\widetilde{r}_4 = (0.2201, 0.2210, 0.2205, 0.1603, 0.1881)\circ R_4 = (0.2205, 0.2210, 0.2210, 0.1854, 0.1749),$$
$$\widetilde{r}_5 = (0.2556, 0.2712, 0.2086, 0.2643)\circ R_5 = (0.2086, 0.2683, 0.2643, 0.2108, 0.2019),$$
$$\widetilde{r}_6 = (0.4202, 0.3602, 0.2196)\circ R_6 = (0.1845, 0.2634, 0.2413, 0.2342, 0.1336).$$

From (7) and (8), using the weight of the level I indexes in Table 1, we get the second level fuzzy evaluation result of total evaluation indicator $\overline{\overline{B}}$ in Feixi County.

$$a\circ R = (0.262, 0.184, 0.12, 0.218, 0.142, 0.074) \circ \begin{bmatrix} 0.2069 & 0.3218 & 0.2564 & 0.2514 & 0.1779 \\ 0.1452 & 0.2131 & 0.2131 & 0.2131 & 0.2131 \\ 0.1874 & 0.2257 & 0.2819 & 0.2431 & 0.2302 \\ 0.2205 & 0.2210 & 0.2210 & 0.1854 & 0.1749 \\ 0.2086 & 0.2683 & 0.2643 & 0.2108 & 0.2019 \\ 0.1845 & 0.2634 & 0.2413 & 0.2342 & 0.1336 \end{bmatrix} = (0.218, 0.262, 0.2564, 0.2514, 0.184).$$

Because the maximum value of each row of matrix R is in the second column, the second column, the third column, the second column, the second column and the second column respectively, and the maximum value of vector $a \circ R$ is in the second column, so for Feixi County, except the quality of indicator B_3 belongs to A_3, the rest of the quality of indicators belongs to A_2. In addition, according to (9), we can calculate the total membership of each indicator in Feixi County. Similarly, by processing the questionnaire data of other counties, we get the rating of each indicator and the corresponding total membership degree of 10 counties, which are listed in Table 10.

investigation on the application of pesticides to rice growers

Next, we take rice as an example to study the relationship between reducing pesticide application intensity and reducing harmful residues in food, as well as the impact on Farmers' income. Because the application of chemical fertilizer is convenient, labor saving and effective, and the price of organic fertilizer is expensive, bulky and bulky, farmers are used to applying more chemical fertilizer. Due to the long-term application of pesticides, pests have developed resistance, less application may reduce crop yield, so farmers usually try to apply as much as possible. Vegetables, especially leafy vegetables grown in summer, are most plagued by pests. Some vegetable farmers spray pesticides once a day or two. The greenhouse vegetables planted in off-season are more prone to insects, and the greenhouse is not easy to ventilate, the pesticide is not easy to emit, and the pesticide residue is heavier than that of open-air vegetables (see the research results of Tang et al. 2012). Because the vegetables planted by different vegetable growers may be different, and the growth periods of various vegetables are also different, there is no comparability in the application of pesticides. In grain crops, wheat mainly grows in cold season, and pesticide is relatively small. Rice and corn are easy to grow insects, and rice planting area is wide. In addition, the growth period of early rice and double cropping late rice is short, the yield is low, and the labor cost is almost the same as that of single cropping late rice. Single cropping late rice has a long growth period and many pesticides, but it has high yield and low labor cost. Farmers like to grow single cropping late rice. The pesticide of early rice is applied less, so the general farmers only grow a small amount of early rice every year, and keep them as their own rations, and then crop the double cropping late rice, and most of the land is planted with single-season late rice. We focused on

Table 9 Fuzzy evaluation matrix of 6 level I indicators of pesticide residues in Feixi County

B_1	$$R_1 = \begin{bmatrix} 0.2069 & 0.3218 & 0.1954 & 0.1609 & 0.1150 \\ 0.2105 & 0.2241 & 0.1862 & 0.2013 & 0.1779 \\ 0.1571 & 0.1964 & 0.3426 & 0.2514 & 0.0525 \end{bmatrix}$$
B_2	$$R_2 = \begin{bmatrix} 0.0254 & 0.2151 & 0.2563 & 0.2824 & 0.2208 \\ 0.1153 & 0.2246 & 0.2906 & 0.3105 & 0.0590 \\ 0.0845 & 0.1683 & 0.2235 & 0.2841 & 0.2396 \\ 0.1232 & 0.2219 & 0.2583 & 0.2453 & 0.1513 \\ 0.1452 & 0.2024 & 0.2431 & 0.2319 & 0.1774 \end{bmatrix}$$
B_3	$$R_3 = \begin{bmatrix} 0.1352 & 0.1463 & 0.2842 & 0.2431 & 0.1912 \\ 0.1874 & 0.1921 & 0.2951 & 0.2418 & 0.0836 \\ 0.1812 & 0.2863 & 0.2243 & 0.2305 & 0.0777 \\ 0.0543 & 0.2257 & 0.2591 & 0.2307 & 0.2302 \end{bmatrix}$$
B_4	$$R_4 = \begin{bmatrix} 0.3124 & 0.2317 & 0.2418 & 0.1243 & 0.0898 \\ 0.2154 & 0.2942 & 0.2218 & 0.1521 & 0.1165 \\ 0.2323 & 0.2547 & 0.2841 & 0.1854 & 0.0435 \\ 0.3321 & 0.2541 & 0.1847 & 0.1125 & 0.1166 \\ 0.1523 & 0.2621 & 0.2361 & 0.1746 & 0.1749 \end{bmatrix}$$
B_5	$$R_5 = \begin{bmatrix} 0.1487 & 0.2524 & 0.2389 & 0.2108 & 0.1492 \\ 0.1320 & 0.2683 & 0.2253 & 0.1725 & 0.2019 \\ 0.3122 & 0.2241 & 0.2014 & 0.1783 & 0.0840 \\ 0.1524 & 0.2319 & 0.2654 & 0.1532 & 0.1971 \end{bmatrix}$$
B_6	$$R_6 = \begin{bmatrix} 0.1461 & 0.2631 & 0.2413 & 0.2342 & 0.1153 \\ 0.1845 & 0.2634 & 0.2341 & 0.1844 & 0.1336 \\ 0.1576 & 0.2853 & 0.2516 & 0.2149 & 0.0916 \end{bmatrix}$$

collecting the main tendency of pesticide application in single cropping late rice. Among the professional rice growers in each county, 480 households (at least 30 and at most 62 in each county) were selected and sent out questionnaires. The questionnaire includes four questions: (1) Do you work hard to prevent your products from being found to have excessive pesticide residues? (2) What do you think is the difficulty of increasing the amount of organic fertilizer in an all-round way at present, and what are the good suggestions. (3) How many times do you usually apply pesticides to early, middle and late rice? How many times do you apply herbicides? (4) What do you think is the extent to which the application of pesticides in accordance with normal conditions can basically ensure that the pesticide residues meet the national standards? For single cropping late rice production, respondents were required to give an interval $[a_i, b_i]$ for each indicator X_i of 13 indicators such as chemical fertilizer, organic fertilizer and pesticide application, and the interval should be as short as possible.

1. Data collection and statistics

453 valid questionnaires were collected. Each indicator value is determined by fuzzy convex membership function method. Let all cells of the ith indicator ($i = 1, 2, \cdots, 13$) be $[a_{ij}, b_{ij}], j = 1, 2, \cdots, 875$. All the intersections of these cells are $\alpha_{i0}, \alpha_{i1}, \cdots, \alpha_{in}$, correspondingly, n intervals $[\alpha_{i0}, \alpha_{i1})$, $[\alpha_{i1}, \alpha_{i2})$,

$\cdots$, $[\alpha_{in-2}, \alpha_{in-1})$, $[\alpha_{in-1}, \alpha_{in}]$ are obtained. Mark the n cells as $A_{i1}, A_{i2}, \cdots, A_{in}$, respectively. In all intervals $[a_{ij}, b_{ij}]$, $j = 1, 2, \cdots, 875$, there is r_{i1} intersection with $[\alpha_{i1}, \alpha_{i2})$ is not empty, there is r_{i2} intersection with $[\alpha_{i2}, \alpha_{i3})$ is not empty, and so on, there are r_{in} final intersection with $[\alpha_{in-1}, \alpha_{in}]$ is not empty. Using X_i to represent the ith evaluation indicator, we can first obtain the $\widetilde{X}_i$ of convex membership number of X_i.

$$\begin{aligned} \widetilde{X}_i &= \mu(X_i) = r_{i1}/A_{i1} + r_{i2}/A_{i2} + \cdots + r_{in}/A_{in} \\ &= (r_{i1}, r_{i2}, \cdots, r_{in}), \end{aligned}$$

Table 10 Classification and summary of food pesticide residues in 10 county farmers' markets

	Feixi	Wuwei	Dangtu	Suixi	Zongyang	Fengyang	Linquan	Taihu	Jinzhai	Jingxian
B_1	A_2 0.4354	A_2 0.4412	A_2 0.4278	A_2 0.4513	A_2 0.4233	A_2 0.4431	A_2 0.4273	A_2 0.4312	A_2 0.4334	A_2 0.4424
B_2	A_2 0.3592	A_3 0.4240	A_2 0.3391	A_3 0.4528	A_3 0.5011	A_3 0.4523	A_3 0.4815	A_2 0.3523	A_4 0.8306	A_4 0.8271
B_3	A_3 0.5949	A_2 0.4014	A_2 0.3915	A_3 0.5852	A_3 0.5623	A_2 0.4253	A_2 0.4022	A_2 0.4715	A_3 0.5724	A_2 0.4117
B_4	A_2 0.4317	A_2 0.4323	A_3 0.5215	A_2 0.4296	A_2 0.4357	A_2 0.4203	A_2 0.4210	A_3 0.5183	A_2 0.4194	A_2 0.4302
B_5	A_2 0.4133	A_3 0.5403	A_2 0.4122	A_2 0.4315	A_3 0.5289	A_3 0.5203	A_3 0.5541	A_2 0.4224	A_4 0.8625	A_4 0.8705
B_6	A_2 0.4237	A_2 0.4228	A_2 0.4324	A_2 0.4295	A_3 0.5618	A_2 0.4364	A_2 0.4327	A_2 0.4386	A_3 0.5705	A_2 0.4231
$\overline{\overline{B}}$	A_2 0.4096	A_3 0.5627	A_2 0.4102	A_2 0.4015	A_3 0.5643	A_3 0.5721	A_3 0.5627	A_2 0.4122	A_4 0.8719	A_4 0.8633

Let

$$L_i = \int_{\alpha_{i0}}^{\alpha_{in}} \widetilde{X}_i dX_i = \sum_{k=1}^{n} r_{ik}(\alpha_{ik} - \alpha_{ik-1}),$$

and we have

$$X_i \sim = \mu \sim (X_i) = (r_{i1}/L_i, r_{i2}/L_i, \cdots, r_{\boldsymbol{in}}/L_i),$$

where $r_{\sim ij} = r_{ij}/L (j = 1, 2, \cdots, n)$. We call $X_{\sim i}$ the standardized convex membership number ofX_i.By direct calculation, we get X_i expected value and variance

$$E(X_i) = \int_{\alpha_{i0}}^{\alpha_{\boldsymbol{in}}} X_i \sim X_i dX_i = \frac{1}{2L_i} \sum_{k=1}^{n} r_{ik} \left(\alpha_{ik}^2 - \alpha_{ik-1}^2\right),$$

$$D(X_i) = \int_{\alpha_{i0}}^{\alpha_{\boldsymbol{in}}} \underset{\sim}{X}_i [X_i - E(X_i)]^2 dX_i$$
$$= \frac{1}{3L_i} \sum_{k=1}^{n} r_{ik} \left(\alpha_{ik}^3 - \alpha_{ik-1}^3\right) - [E(X_i)]^2.$$

We set the evaluation value of X_i as $E(X_i)$, and use $D(X_i)$ to judge the degree of concentration of the results of the questionnaire, that is, the credibility of the results. The smaller $D(X_i)$ is, the more credible it is. If $D(X_i)$ is too large, consider eliminating some interview results that are too different from $E(X_i)$. However, $D(X_i)$ cannot exceed much, there is no absolute standard at present, generally determined according to experience. Finally, the data are sorted out as shown in Table 11:

Among them, comprehensive labor includes labor tool loss, breeding, fertilization, pesticide application, and field management; harvesting has been fully mechanized; and seedling planting on large land has also been mechanized. The statistical results of the four questions are as follows: (1) All respondents wanted to avoid exceeding the standard of agricultural residues in the products harvested, but they were more worried about the reduction of production. (2) More than 87% of the respondents believed that the main reason was that the price of organic fertilizer was high and the effect of organic fertilizer was slow. Excessive application of organic fertilizer immediately might affect the current yield. The important measure to expand the source of organic fertilizer was to realize the cooperation between planting and animal husbandry. Therefore, the average proportion of organic fertilizer is only 20.1%. (3) Early rice, double cropping late rice and single cropping late rice were sprayed with insecticide 3 times, 7 times and 8 times respectively. Generally, herbicides were applied twice in each season. There are mainly two kinds of chemical fertilizers used in rice. Before planting seedlings, more compound chemical fertilizers are used as base fertilizer, and then nitrogen fertilizer is added 2-3 times according to the growth of seedlings. (4) According to the experience of 79% of the respondents, if the control effect is controlled within 85%, the pesticide residues can basically pass the test.

2. Parameter estimation

According to (10), in this paper, we take $C(T) = 1 - exp(-mT)$; thus, we get

$$y = ax_1^{\beta_1} x_2^{\beta_2}(1-\delta) + \delta a x_1^{\beta_1} x_2^{\beta_2}[1 - exp(-mT)], \tag{11}$$

where $y = X_1$, $x_1 = X_4$, $x_2 = X_5 + X_7 + X_{12}$, $T = X_6$, $C(T) = X_8$ (see Table 11). Let δ be about 0.3, and from (11) we get the regression equation

$$\widehat{y}/\left(1 - 0.3e^{-mT}\right) = ax_1^{\beta_1} x_2^{\beta_2}. \tag{12}$$

In order to estimate the parameters of regression equation (12), we do it in two steps.

Step 1 Because $m = -\frac{1}{T} Ln[1 - C(T)]$, according to the original sample data of pesticide input and pest control effect collected from 10 counties, the moment estimation method is used to obtain the estimated value of m in (11).

$$\widehat{m} = -\frac{1}{875} \sum_{j=1}^{875} n\left[1 - C\left(T_j\right)\right] / T_j L = 0.02186. \tag{13}$$

Table 11 Production cost, yield and price of single cropping late rice in 10 counties

	$E(X_i)$	α_{in}	α_{i0}	$\sqrt{D(X_i)}$
Per mu yield X_1 (kg)	507.8	518	490	32.6
Price X_2 (yuan/kg)	4.2	4.5	4.0	0.26
Seed X_3 (yuan/mu)	27.3	29.0	26.0	2.2
Fertilizer X_4 (yuan/mu)	122.8	152.0	104.5	22.7
Apply fertilizer X_5 (yuan/mu)	102.8	122.0	97.5	20.5
Pesticides X_6 (yuan/mu)	105.2	131.5	97.5	30.4
Application X_7 (yuan/mu)	102.1	113.5	97.5	18.7
Application effect X_8 (%)	90.1	92.5	86.0	3.6
Tractor-ploughing X_9 (yuan/mu)	102.0	112.5	88.0	8.7
Agricultural film X_{10} (yuan/mu)	7.1	8.0	6.5	0.8
Irrigation X_{11} (yuan/mu)	10.2	11.0	10.0	0.91
Comprehensive labor X_{12} (yuan/mu)	195.2	235.0	172.0	17.3
Proportion of organic fertilizer X_{13} (%)	20.1	31.0	16.5	3.3

Note: According to the experience of 79% of the respondents, if the control effect is controlled within 85%, the pesticide residues can basically pass the test

where $T_j = (a_{6j} + b_{6j})/2$, that is the average value of pesticide application intensity given by interviewee j-th. Similarly, $C(T_j) = (a_{8j} + b_{8j})/2$.

Step 2 $y^* = Ln[y/(1-0.3e^{-0.02186T})], x_1^* = Lnx_1, x_2^* = Lnx_2, a^* = Lna$, is recorded, and (12) is transformed into binary linear regression equation

$$\hat{y}_i^* = a^* + \beta_1 x_{1i}^* + \beta_2 x_{2i}^* (i = 1, 2, \cdots, n). \quad (14)$$

Using the data of 453 sample households and Mathematica software, the estimation can be obtained by the ordinary least squares method.

$$\hat{a}^* = 1.59066, \hat{\beta}_1 = 0.211, \hat{\beta}_2 = 0.61,$$

so $\hat{a} = 4.907$, (11) is

$$\hat{y}_j = 4.907 x_{1j}^{0.211} x_{2j}^{0.61} \left(1-0.3e^{-0.02186T_j}\right) (j = 1, 2, \cdots, 453). \quad (15)$$

The regression equation of rice Damage-abatement production function is obtained.

3. Validity test

The validity of the equation (14) was tested by F-test, and $H_0: \beta_1 = \beta_2 = 0$ is assumed. Let $Q_e = \sum_{i=1}^{30} (y_i - \hat{y}_i)^2, U = \sum_{i=1}^{30} (y_i - \overline{y})^2, F = \frac{U/2}{Q_e/(30-2-1)}$. directly from the sample data and (14), we can directly calculate $F = 23.84$. Taking the significance level $\alpha = 0.05$, we look up the critical value table and get the critical value $F_{0.95}(2, 27) = 19.5 < 23.84$, that is, we refuse to assume H_0, so the regression equation (14) is valid, and further (15) is valid. Equation (15) shows that the contribution rate β_2 of labor input to rice yield in the investigated area is much larger than that of fertilizer β_1. The main reason is that too much fertilizer is used in rice production at present, and the effect of fertilizer on rice yield is extremely weak. The effect of field management on rice yield is still very significant.

Results and analysis

Analysis of pesticide residues exceeding the standard

According to Table 4, Table 6, Table 8 and Table 10, we calculated the average value of harmful residues in 10 cities and 10 counties respectively, and obtained the total standard situation of harmful residues in agricultural products consumed in urban and rural areas (see Table 12 and Fig. 2). In order to change the compliance degree of pesticide residues in rural food market into percentage, we first regard A_1, A_2, A_3, A_4 and A_5 as 100%, 80%, 60%, 40% and 20% respectively, and then calculate according to the following method. If the index B_i (or $\overline{\overline{B}}$) of a county reaches grade A_j and the total membership degree is $\widetilde{S}_i$ (or $\widetilde{S}_T$), then the standard degree of index B_i (or $\overline{\overline{B}}$) of the county is $20\%\left(5-j+\widetilde{S}_i\right)$ +5%, or $20\%\left(5-j+\widetilde{S}_T\right)$ +5%. If we count the quality up to A_j as just above the bottom line, it is obviously too low, so we increase it by 5%. For example, the first level indicator B_1 of Feixi County reaches A_2 level with membership degree of

Table 12 Summary of pesticide residue detection and questionnaire of edible agricultural products

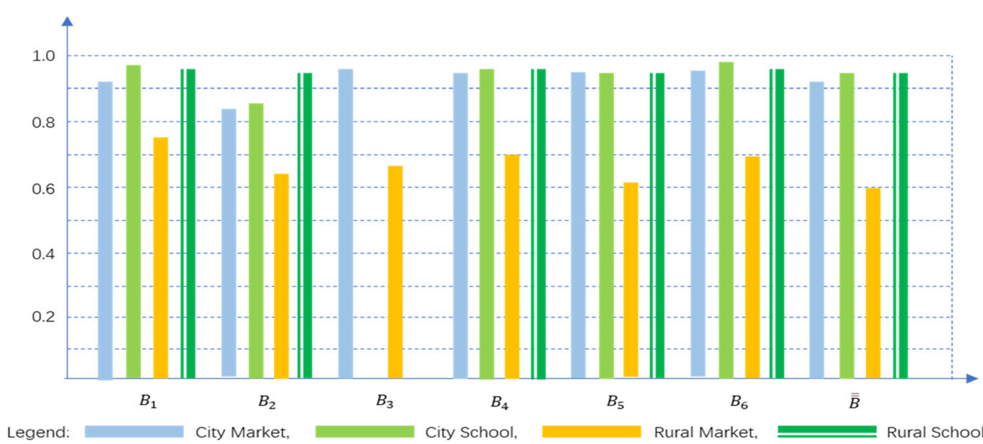
	B_1	B_2	B_3	B_4	B_5	B_6	$\overline{\overline{B}}$
City market	93.078	84.799	97.120	95.374	95.435	94.907	92.961
City school	97.453	85.377	*	97.820	96.479	98.083	94.812
Rural market	73.6928	65.04	67.6368	69.92	61.112	70.143	60.261
Rural school	97.144	86.055	*	97.422	96.381	98.010	94.894

0.4354, that is, the first level indicator B_1 of Feixi County reaches A_3 level or above, so the compliance degree of the first level indicator B_1 of Feixi County is evaluated as $20\,\%\,(5-2+0.4354)+5\,\%\;=73.708\,\%$.

In urban and rural schools, except for vegetable indicator B_2, which was 85.377% and 86.055% respectively, the other four level I indicators and comprehensive indicator $\overline{\overline{B}}$ were all around 95%. In the urban farmer's market, except for vegetable indicator B_2, which only reached 84.779%, the other five level I indicators and comprehensive indicator $\overline{\overline{B}}$ reached 92.961–97.12%. In the rural market, only B_1 and B_6 are slightly higher than 70% of the standard, and the other indicators are slightly higher than 60% of the standard. A careful review of Table 10 shows that there is a large gap in the degree of reaching the standard of pesticide residues among counties. Feixi, Dangtu, Suixi and Taihu counties, which are relatively developed, are slightly better than Jinzhai and Jing counties, which are relatively backward in mountainous areas. It may be that rural people with better economic conditions pay more attention to pesticide residues when buying food, and producers must be more cautious when applying pesticides.

In addition, in the market survey, we noticed that the vast majority of edible agricultural products consumed by urban residents come from large-scale farmers' markets. The total amount of individual businesses and night markets is very small, and individual businesses are also monitored to a certain extent. Therefore, we estimate that at least 95% of edible agricultural products consumed by urban residents is under the supervision of the government. All urban school canteens are under the supervision of the government. Although rural school canteens are under strict management, especially many schools often conduct self inspection, the inspection interval of the supervision department is generally two months. So we assume that 95% of the rural school canteens are monitored by the government. For the edible agricultural products consumed by rural residents, only livestock and poultry are slaughtered intensively, and random sampling is carried out for the feeding process of large-scale farms, so the safety performance of meat food is basically guaranteed. For the planting industry, the main measures are to guide and encourage farmers to use less chemical fertilizers and pesticides, and the monopoly system and real name system are adopted for the purchase of chemical fertilizers and pesticides and veterinary drugs. Considering that the implementation of centralized slaughtering system may not be strict, we estimate that the government's monitoring degree on the production of edible agricultural products is about 30%. In addition, for the questionnaire survey of the rural market, although we mainly choose housewives who know the most about food quality as the respondents, we feel that the respondents tend to give high evaluation as much as possible. Therefore, the comprehensive compliance rate of rural residents' consumption of edible agricultural products reflected in Table 10 is 60.261%. We estimate that it may be less than 60% in fact, that is, it obviously exceeds the standard. At present, the theoretical accuracy rate of rapid detection instruments used in the market is 95%, but

Fig. 2 Total results of pesticide residues test and questionnaire of edible agricultural products (%)



in order to speed up the promotion of rapid detection technology, the government has a low threshold for the production access of detection instruments, and the production enterprises are mixed. According to some market testers, the actual accuracy of testing instruments is about 90%. We use Fig. 3 to describe the overall actual situation of harmful residues in edible agricultural products.

Figure 3 shows that the food safety rate of school canteens is the highest, and the food safety of rural school canteens is not different from that of urban ones. The safety of edible agricultural products consumed by urban residents basically reached 80%. Only the residues of harmful substances in edible agricultural products consumed by rural residents obviously exceeded the standard. The food suppliers of the school canteen know that the school is strict, and they automatically try to avoid providing items with excessive pesticide residues. The fact also shows that the producers of agricultural products know the degree of pesticide residues in the food they provide.

Analysis on the causes of excessive pesticide residues in edible agricultural products

Using (12), we can estimate the profit of rice production per mu

$$R_j = \widehat{y}_j X_{2j} - (X_3 + X_4 + \cdots + X_8 + X_{10} + X_{11} + X_{12}).$$

For example, according to Table 11, the average profit per mu of 543 households is 1358.06 yuan. In the rice production of the *j*-th cooperative, if the input per mu is $x_1 = 115.8$ yuan for chemical fertilizer, $x_2 = 339.4$ yuan for labor and $T_j = 105$ yuan for pesticide, the application effect $C(T_j) = 0.96978$, the yield per mu is $y_j = 500.95$ kg and the profit per mu is $R_j =$ 1212.19 yuan. According to the notes in the last line of Table 11, the *j*-th cooperative now plans to control the pest control effect below 85%, so that the pesticide residue may reach the standard, that is, $1 - 0.3e^{-0.02186T_j} < 0.85$, then the pesticide application intensity $T_j < 31.71$ yuan. The yield per mu is $y_j = 439.07$ kg, and the profit per mu is reduced to $R_j =$ 1028.23 yuan. Therefore, the cooperative would rather apply more pesticides than bear the consequences of lower production. This is also a common phenomenon in all crop cultivation. It can be seen that the phenomenon of excessive pesticide residues in agricultural source food is not optimistic. According to the research of scholars, only about 20% of the pesticides are absorbed by crops (Wang and Gu 2013), and only 20% of the pesticides absorbed by crops are contained in rice, and the rest is in straw (Zhang et al. 2011). In addition, according to the experience of farmers, the pesticide residues in rice will be further attenuated when rice is stored at home for a period of time, so the pesticide residues in rice are not particularly serious. For vegetables that are not protected by thick skin outside, pesticides usually directly enter into vegetables, and vegetables cannot be stored at home for a long time, so the pesticide residues in vegetables are the most serious.

Conclusion

Through the detection of pesticide residues in sales channels, it can greatly reduce the excessive pesticide residues in agricultural products. Edible agricultural products in Chinese cities and all kinds of school canteens are strictly tested for pesticide residues. On the whole, the pesticide residues in agricultural products are in a controllable

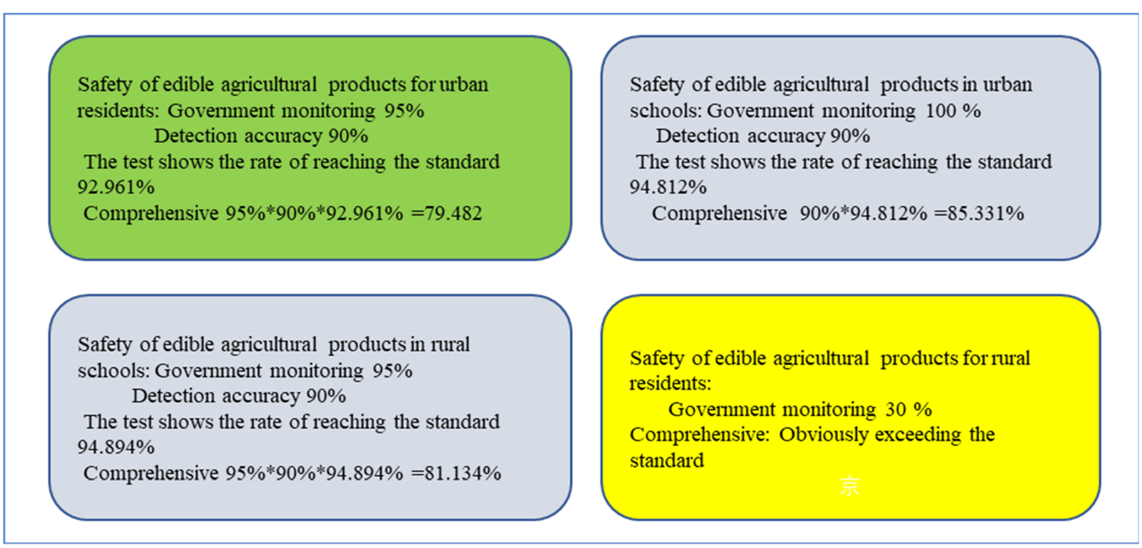


Fig. 3 The overall actual situation of harmful residues in edible agricultural products

range. First of all, there are still some defects in market detection: (1) The accuracy of rapid detection can reach 95% in theory, but it may be even lower in practice. The detection results can only play a role in preliminary investigation. In some markets, we have learned from our exchanges with operators that for the food that is found to be unqualified after investigation, it is generally only required to stop selling, not to investigate the source, not to punish and not to publicize. Moreover, every market sells a lot of agricultural products every day, and the proportion of random sampling is still too small, so the problem food must exist objectively (see the case in the introduction). (2) For the qualified food, the detection does not distinguish the specific degree of food residue, and lacks incentive mechanism for the operators of slightly better quality food. (3) Because the county, town, market town and the farmers' market in rural areas have not yet established the detection system of pesticide residues, it is inevitable that the edible agricultural products which does not meet the standard of pesticide residues will flow into the suburbs, roadside restaurants and rural areas. In particular, influenced by COVID-19, the government has liberalized the stall economy, and some unlicensed vegetables and fruit stalls on the streets have not been able to control the pesticide residues. Secondly, the risks of agricultural products reduction and pesticide residues borne by farmers are obviously asymmetric. Although governments at all levels have been guiding and rewarding farmers to use fertilizers, pesticides and veterinary drugs rationally, they are unable to strictly supervise the production process of farmers. According to Damage-abatement production function including pesticide factors, under certain conditions of fertilizer and labor input, rice yield and pesticide residue intensity are positively correlated with pesticide application intensity input, and most farmers know that rational application of pesticide can reduce pesticide residue. Reducing the use of pesticides will inevitably bear the risk of reducing the output of agricultural products, and applying more pesticides will increase the risk of pesticide residues. As the current farmers' market is not very strict on the detection of pesticide residues, farmers need to bear the risk of pesticide residues is very small. Driven by economic interests, farmers prefer to increase the intensity of pesticide application. Thirdly, the production cost and income of agricultural products are asymmetric. The cost of agricultural production is rising, but due to the influence of low prices in the international market and the low income of most people in China, the price of edible agricultural products is unlikely to rise significantly. Limited by financial resources, local governments cannot give too high subsidies to agricultural production reduction. What is more important is that there are too many people and too little land in China. If there is a large reduction in grain production, it will cause food shortage. Food belongs to strategic materials and cannot be heavily imported. Therefore, it is impossible to comprehensively promote the pesticide residue detection system in the short term, and the qualified standard will not be set too high. In recent years, China has taken measures such as resuming the consumption tax of chemical fertilizer, increasing the subsidy for organic fertilizer application, promoting the technology of soil testing and fertilization, processing organic fertilizer with garbage, and forcing livestock manure to process organic fertilizer. Gradually increasing the proportion of organic fertilizer in agricultural production will become a reality. Before there is a major breakthrough in the development of biological pest control technology, it may still be a protracted war to achieve a substantial reduction in the use of pesticides and veterinary drugs, which may also be a world problem.

The development of society has never been smooth sailing, but spiraling. The progress of agricultural science and technology, in reducing crop diseases and pests, improve food production, reduce the risk of hunger, at the same time, increase the risk of food pollution. Just like the progress of transportation, it brings convenience for people to travel, but increases the risk of traffic accidents. The food pollution risk is mainly affected by low-income groups, especially the majority of rural residents. Some people compare the difference between urban and rural areas in China to "cities like Europe, rural areas like Africa", which may still exist in the short term.

Of course, Chinese farmers generally lack scientific knowledge of pesticides, and their application behavior is blind, especially the law of pesticide application interval and pesticide residues cannot be accurately grasped. Strengthening the popularization of agricultural science and technology knowledge as soon as possible is an important link in the implementation of pesticide reduction measures. However, with the development of rapid detection technology, the price of simple rapid detection instrument is very cheap, and it may be popularized to families in the near future. The residues of harmful substances in food will become more and more transparent, and the food safety of the whole people will be greatly improved.

However, with the development of rapid detection technology, the price of simple rapid detection instrument is very cheap. It may be popularized to families in the near future, and the food safety of the whole people will be greatly improved.

There are two deficiencies in our research: (1) The information we have obtained from our investigation is limited, so it is certainly not comprehensive enough to reflect the problems in Chinese food. In particular, the results of the questionnaire survey in rural farmers' markets can only reflect part of the real situation of food pesticide residues in rural areas. (2)

As the rural market did not implement pesticide residue detection, some fake and inferior food processed by black workshops were mainly sold in rural areas. For example, bean products processed with rotten and deteriorated soybeans (added with a toxic bleaching agent "suspended white block"), fruits ripened by spraying drugs, gutter oil, etc. In 2018, Nanjing police intercepted a batch of zombie meat illegally entering the country. In the vast rural farmers' markets, how many of these harmful fake and inferior food are mixed with normal food. Due to the lack of reliable data, we did not study it.

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Data availability The data and materials used in this paper come from four aspects: (1) published journal papers; (2) public statistical information published by government departments; (3) visit survey of our research group. It does not involve infringement of the interests and rights of any enterprise or individual. All data generated or analysed during this study are included in this published article [and its supplementary information files].

Declarations

Ethics approval and consent to participate Not applicable

Consent for publication Not applicable

Conflict of interest Professor Tao Sun is Wei Xu's doctoral supervisor. The relationship between the two is harmonious and there is no conflict of interest. There is no conflict of interest with any other organization or individual.

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