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"Poisonous" innovation: an intellectual-ethical analysis based on China's paraquat

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Author contributions

Dong KJ conceived the concept for this paper and contributed mainly to its completion. Hao ZH refined the part of ethical discussion.

Competing interests

The authors declare no conflicts of interest.

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Abbreviations

PQ, Paraquat; DDT, Dichloro diphenyl trichloroethane; HPLC, High-Performance Liquid Chromatography.

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Abstract

Background: The successful application of technological innovation in chemicals ultimately involves many uncertainties. Despite its reliable performance and excellent effectiveness in application fields, China's paraquat was ultimately banned due to its use as a poison by some suicides. **Methods:** To prevent similar occurrences, this paper adopts a research method combining "ethical analysis and intellectual analysis" to study the two uses of paraquat as a chemical and a poison. **Results:** (1) Even with a high degree of professional ethical standards, incidents that harm societal interests may still occur. Furthermore, the misuse of a product in areas beyond its intended scope may expose the product to social responsibilities. (2) An individual technological innovation must be coordinated with the overall techno-economic paradigm. (3) In the field of chemical products, as well as in many new product areas, development driven by a "polarized" mindset, despite achieving breakthroughs in certain indicators, may potentially cause systemic harm. **Conclusion**: It ultimately proposes upgrades in production and lifestyle, requiring simultaneous innovation in "technology + management systems," emphasizing the importance of product degradation from the initial research and development stage, and calling for the involvement and expertise of healthcare professionals throughout the entire industrial process.

Keywords: paraquat; ethical analysis; intellectual analysis

Introduction

There exists a class of medications whose efficacy is neither to treat illnesses, restore health, nor enhance physical constitution; nor are they pseudo-medications serving as placebos. Instead, they are used to end human life. Such medications can be termed lethal agents. Among them, there are hotly debated euthanasia drugs (such as potassium cyanide and sodium cyanide), hypnotics (barbiturates, benzodiazepines, and non-benzodiazepines), and a more special type of poison-potent suicide drugs.

Since prehistoric times, humans have practiced euthanasia, and following the 1960s and 1970s, multiple countries have passed euthanasia acts, allowing and approving terminally ill patients to die with dignity and to alleviate their suffering, either on their own or with the assistance of doctors and relatives. Francis Bacon once referred to this as a method of "painless lethality." This practice is regarded as a humane act towards those in a hopeless condition. However, for those who are physically functional but suicidal due to a disinterest in life, no country advocates for such behavior. Émile Durkheim, in his book "*Le suicide*," identified four types of suicide: egoistic suicide, altruistic suicide, anomie suicide, and fatalistic suicide, all of which arise from obstacles and alienation in the individual's relationship with society [1]. Regarding the use of drugs for suicide, regardless of the type, national authorities exercise extremely strict control over the distribution and sale of these medications. Therefore, suicides often resort to non-euthanasia, non-hypnotic drugs, which are the potent suicide drugs mentioned earlier. One particular drug, due to its immense harm, is known as the "water of death"-this is paraquat (PQ ,Baicaoku).

In 2024, new cases of PQ poisoning occurred in China again [2]. This incident came exactly ten years after the initial revocation of the production license for paraquat aqueous solution on 1 July 2014. Subsequently, in July 2016 and September 2020, China imposed two more bans on the sale and use of paraquat aqueous solution and paraquat gel within its territory. On China's list of restricted pesticides, paraquat is prominently listed as one of the 56 pesticides. However, paraquat pesticides still remaining in farmers' homes continue to be the culprit and hidden danger behind similar tragic lessons in recent years.

Learning from past mistakes and reflecting inwardly, can the tremendous harm caused by paraquat be avoided or greatly reduced? In other words, can similar incidents in the future be fundamentally eliminated?

Case background

Paraquat (PQ), also known as Diquat, and Gramoxone, is a fast-acting contact herbicide. Its main component is dimethyl dichloropyridine, with the molecular formula $C_{12}H_{14}Cl_2N_2$.

In its pure crystalline state, it is white or light yellow, easily soluble in water at room temperature, with a density of approximately 1.2 g/cm^3. Its active ingredient exhibits extremely strong destructive power against the chloroplast lamella of crops, rapidly terminating photosynthesis. Leaves exposed to the herbicide will discolor and wither within about 2 to 3 h. Due to its remarkable herbicidal efficacy, it is suitable for both forestry operations and the spraying of weeds in field crops, effectively controlling both annual and perennial weeds.

When used correctly, PQ is a cost-effective, fast-acting, rain-resistant, and no-till herbicide with the advantage of "zero residue," earning it the title of "king of herbicides." However, if ingested accidentally or intentionally, it is rapidly absorbed by the body's aqueous tissues, spreads quickly, and accumulates in internal organs. The main symptom of poisoning is gradual fibrosis of the lungs, leading to irreversible asphyxiation in adults with just 3 mL ingestion.

In terms of emergency treatment and detoxification mechanisms, although almost all pesticides are toxic, PQ has an extremely high fatality rate (above 90%). Due to its minimal solubility in organic solvents, once it contacts human organs, it is difficult to separate it from the tissue using biochemical techniques, which is one of the reasons why there is no specific antidote (almost "unsolvable").

What requires our reflection is that before the joint sales ban issued by China's Ministry of Agriculture, Ministry of Industry and Information Technology, and General Administration of Quality Supervision, Inspection and Quarantine, paraquat was a fully patented, environmentally friendly, and important technological innovation with the world's largest production capacity. Unlike the eventual global ban on the production and sale of DDT, as advocated in "Silent Spring" [3], more than half of the countries worldwide still use this technology. Moreover, despite the frequent poisoning cases of paraquat in China, they are relatively rare in the United States, Japan, and Europe, and are mostly due to misuse. This is why, despite being banned in China, paraquat is still exported in large quantities to earn foreign exchange. Based on existing facts, the direct reason for the ban on paraquat in China is its toxicity, mainly due to its use as an unsolvable suicide drug. Under the ban, it seems that paraquat has borne the blame for misuse that it should not have, leading to more than 300,000 practitioners being forced to switch careers [4]. So, what decision-making process did this product undergo from its inception to production and ultimate ban? From the initial research and development to the discovery of its hazards, did intellectual decision-making and ethical value judgments influence the innovation process and how? Were corresponding early warning and remedial measures implemented, and why were they ineffective? Behind the paradoxical and astonishing reality, there are logics that require our serious consideration.

Theoretical background

Since Socrates' discussions on "What is Justice," through Plato's "Republic," to Aristotle's "Nicomachean Ethics," the edifice of ethics, an essential component of the philosophical system, has been established. However, this edifice is fluid. That is, it primarily evolves along the two major branches of virtue ethics and intellectual ethics, sometimes diverging and sometimes converging.

One of the mainstreams, or trunks, within this flow is virtue ethics, which primarily concerns "how to live virtuously," or "how to be a good person." A "good person" can be understood, in a sense, as an individual with admirable internal states who can choose any action within their capacity that they enjoy doing, without any diminution or reduction in the admirability or goodness of their behavior [5]. One of the issues involved here is the issue of premises. It is inherently assumed that only actions performed by individuals with good motives are justified. In other words, a noble action is considered benign if and only if it is performed by a noble or virtuous person. This is also Aristotle's main view: virtue is based on the agent, and the virtuous individual serves as the measure of virtue in action. Under this perspective, the task of ethics becomes cultivating virtuous individuals and preserving their virtue. For those lacking virtue, to perform virtuous actions, they must be guided by virtuous individuals. For virtuous individuals, their motives for acting virtuously are entirely natural, and with full consciousness and ability, they can easily distinguish between "what is good and what is wrong" and act accordingly. This intuitionistic virtuous individual possesses a classical aesthetic and intuition. The second issue is the central problem, meaning what serves as the criterion for judging good and evil. When interests originate from diverse and multiple perspectives, the actor can only achieve intuitive virtuous actions by centering on themselves, which may not align with the virtue judgments of other actors. Killing a terminally ill cow may stem from the benevolent intention of alleviating its suffering, but it may also provoke great outrage and hostility from followers who view cows as deities. To address this dilemma, Plato's view is that although it is always the individual "I" as the actor who makes judgments and takes actions, the standard of good and evil is not purely individual but a collective "we" of shared virtuous habits. In this case, actions centered on the actor are virtuous actions and are guaranteed to be so. The third issue is the issue of outcomes. Because there is the possibility of malicious actors performing virtuous actions, and these actions are recognized by non-actors outside the individual actor. For example, Sidgwick discusses a scenario where a prosecutor, motivated by malice, exposes and punishes criminals. Does this situation apply to the standard of "living virtuously?" That is, when faced with "malicious virtuous actions," should society encourage, recognize, or continue to condemn them? Obviously, ethics has recognized that even if a virtuous action with beneficial consequences arises from malice, if generalized malice would bring immeasurable destruction, such behavior, although positively effective in that specific instance, should never be defended. This short-lived beneficial effect is certainly not desirable. Because if any character could potentially lead to good outcomes, then distinguishing between kind motives would seem unnecessary, which would completely undermine the foundation of ethics! "It seems that only good motives are meritorious," Hume hits the nail on the head [6].

Intellectual ethics represents another stream, gradually evolving from serving as a supplement to virtue ethics to almost supplanting its dominant position. The intellectual branch exposes the vulnerability that the virtue branch cannot address. Firstly, motives are unmeasurable. Regardless of whether the motive is good or not, it is usually only known to the actor themselves. Even if it can be observed and verified by others, it would require tremendous effort, and such observation and verification are often unreliable due to the involvement of a third party's virtue motive. Secondly, virtue motives focus too much on the moral life of individuals, whereas society as a whole is not merely a simple aggregation of individuals. This relates to the handling of the issue of universal benevolence. In a situation where a virtuous husband finds his wife and a stranger drowning simultaneously, which one should he rescue first to be considered more virtuous? Obviously, rescuing his wife, with whom he has a deep emotional bond, aligns with virtue, but this contradicts the higher demand for universal benevolence. Virtue ethics thus relies on intuition and the heart in such dilemmas, yet it does not provide a perfect solution. Furthermore, outcomes are actually unmeasurable with precision. Besides the "part-whole" mismatch similar to the issue of "universal benevolence" in scope, the virtue of an action can also change over different stages. Ultimately, intellectual ethics proposes a new hypothesis: Even if an individual has good motives, their actions may not align with benevolent deeds, and they may lack sufficient ability to recognize which actions can lead to greater good. In such cases, their actions can hardly be termed as "a virtuous life." Since then, normative ethics has gradually overshadowed virtue ethics [7].

Addressing the issues surrounding paraquat can be challenging, as it is prone to biases if approached solely from a moral or purely rational perspective. Intellectual ethics, like a stream flowing from amidst numerous mountains, offers a different perspective. This article intends to adopt a primarily "intellectual analysis + ethical analysis" cross-methodology to explore these issues both vertically and horizontally. Meanwhile, based on the dual use (or misuse) of paraquat as both a pesticide and a poison, the discussion will be divided into two scenarios.

Paraquat as an agricultural chemical

Intellectual analysis

Selection of technical routes and preliminary evaluation. Paraquat was first invented in the United Kingdom. In 1955, ICI (the predecessor of Syngenta) discovered the herbicidal activity of bipyridinium quaternary ammonium salt and officially launched it onto the market in 1962. This product gained popularity due to its lack of pesticide residue, allowing for subsequent crops to be planted directly after application. It similarly won the favor and was widely used by Chinese farmers more than three decades later.

In China, the birth of paraquat originated from the Shandong Pesticide Research Institute in Jinan (now known as Shandong Academy of Pesticide Sciences, hereinafter referred to as Shandong Institute). Throughout its development, the research and use of pesticides have been almost synchronized with the pace of China's reform and opening-up.

Pesticides are mainly divided into three categories: insecticides, fungicides, and herbicides. In the early days after the founding of the People's Republic of China, the basic composition of pesticides was insecticides such as DDT and Benzene Hexachloride (BHC), marking the beginning of the development of the domestic pesticide industry. During this period, growth regulators were also developed and put into use. By 1978, the toxic and side effects of DDT and Benzene Hexachloride (BHC) were gradually recognized, leading to their ban on production and use in 1983. At this time, insecticides still accounted for more than 90% of the total pesticide production.

In the late 1950s, China already had a small amount of herbicides, but in 1978, the total production of herbicides (active ingredients) was only 22,047 tons, accounting for 4.1% of the total pesticide production. The largest users were mainly production and construction corps, agricultural reclamation systems, and state-owned farms, while the vast rural areas still relied on manual weeding (the weeds collected were also used as feed for rural livestock). In 1978, the reform and opening-up policy led to the gradual implementation of the household contract responsibility system in rural areas, greatly improving farmers' enthusiasm. With "not enough land to cultivate," a large number of farmers migrated to cities and towns to become a new generation of migrant workers. In this context, the traditional farming habits of intensively using a large amount of labor for manual weeding became unsustainable due to the decline in rural labor force. Additionally, as rural areas gradually became more affluent, especially in coastal and riverine regions such as Jiangsu and Zhejiang, the demand for herbicides in rural areas soared uncontrollably. The booming pesticide industrialization was an inevitable result of the further deepening of the reform and opening-up policy.

When establishing its research direction, Shandong Institute was extremely cautious and concentrated its limited research funds on the most critical areas, choosing the relatively niche field of herbicides. At that time, the northern and southern centers for pesticide research in China encompassed 21 scientific research institutes and 6 pesticide experimental bases, with fungicides as the main focus during the Ninth Five-Year Plan period (of the 32 approved research projects, 16 were fungicides). Even within the field of herbicides, Shandong Institute faced stiff competition from domestic research peers. Taking the approved projects as examples, monosulfuron, monosulfuron-ester, pyrazosulfuron-ethyl, ipyrazosulfuron, dimethametryn, sulfometuron-methyl, and chlorphoxim were all controlled by the northern and southern centers, making it almost impossible to win in direct competition. Shandong Institute ultimately chose a project that seemed to be overlooked by others-paraquat (which had been maturely used abroad for decades, and the production and product patents had expired). However, in terms of technology, it targeted the "world's most advanced method" at that time, specifically the "new process for producing paraquat using liquid ammonia." The reasons for this choice were limited competition, high difficulty, and more importantly, broad potential applications. The subsequent journey proved that Shandong Institute's ability to stand out in the domestic pesticide field was directly related to this decision.

Independent breakthroughs and innovative improvements in production processes. The path of innovation is exceptionally challenging. This is also the reason for the limited competition in this project, which ensured that Shandong Institute could focus solely on research and development without worrying about being surpassed by powerful sibling institutions. Shandong Institute faced three major challenges in its research and development: First, the traditional process for PQ production is the sodium metal method (sodium fusion method). While the sodium metal method is mature and produces low-priced products, it has the disadvantage that intermediates are carcinogenic. Shandong Institute had to skip low-level exploration and directly start with the high-end aminocyanide method, rather than learning through practice from the sodium metal method. Second, liquid ammonia is an extremely dangerous reaction medium with low temperature and high pressure. From the laboratory to small-scale tests, pilot tests, and continuous large-scale industrial production, a very high degree of process stability is required. The emission and recycling of waste during production also need to be explored independently. Shandong Institute, together with its partners, successfully experimented with automation and intelligent control technologies. Third, one of the raw materials for PQ is pyridine, whose production process was not mastered by China at that time. When Shandong Institute's research and development achieved initial success, the price of pyridine suddenly rose by nearly 300% overnight, almost dealing a devastating blow to the experiment and threatening to disrupt it. Fortunately, in 2002, Nanjing Red Sun timely overcame the difficulty of pyridine production. Shandong Institute then pressed ahead and cooperated with sibling institutions to establish a complete upstream and downstream industrial chain for paraquat, thereby forming a complete pesticide research, production, and sales system that is not controlled by foreign capital.

It must be clarified that the production of PQ, strictly speaking, belongs to the industry of agrochemicals, specifically the pesticide chemical industry. Due to the high-tech and large-scale nature of pesticides, their research and development are primarily concentrated in universities, scientific research institutes, and large companies, while their production is often controlled by a few to dozens of companies that have formed oligopolies within the industry. Additionally, agriculture holds a fundamental strategic position in all countries. Under such circumstances, the research and development, production, sales, and use of pesticides are usually subject to close attention and regulation by the governments of the respective countries.

From 1996 to 2004, after an eight-year battle, China developed its own PQ and became the second country in the world, after Syngenta UK, to fully master its production process. Representatives from Syngenta's UK headquarters visited specifically to learn and verify the process, and found that the paraquat produced by Shandong Institute contained fewer impurities, had higher purity, and ranked first in multiple indicators globally (Table 1). It is precisely due to the clean, continuous, and automated production process that not only domestic demand is met, but also significant exports are achieved, making paraquat a flagship product in the total pesticide exports and a source of "great pride" for Shandong Institute.

After being tested over a long period in practice, PQ has been recognized as an "excellent product" within the pesticide group, characterized by green production processes, convenient use, low price, environmental and ecological safety, and food safety.

Table 1 Characteristics of paraquat products and their production processes

Technical characteristics	Comparison items	Advantage description
Easily soluble in water	Most pesticides are insoluble in water and need to be transformed into sprays using emulsifiable concentrates or other organic solvents. These emulsifiable concentrates, which have no pesticidal effect, ultimately end up largely in the air and soil.	Paraquat is easily soluble in water and can be diluted with water. It does not involve pollution from additional additives.
	Conductive pesticides, if sprayed onto agricultural crops by mistake, can cause the entire plant to wilt.	If paraquat is splashed onto a single spot on a crop, it will create a hole but will not conduct further. The crop will continue to grow.
Non-conductivity	Deactivation upon contact with soil	The hazards of pesticides will not persist in the soil and will not harm the roots of crops.
	Soil and water conservation	Nor will they harm the roots of weeds. However, after the aboveground parts of the weeds wither, the crops grow tall quickly, and sunlight and moisture tend to favor the crops, making it difficult for the weeds to harm the crops. Meanwhile, since the roots of the weeds are not killed, this is beneficial for soil and water conservation, especially in hilly areas.
Quick effectiveness	General pesticide herbicides usually take 2–3 days to take effect. Additionally, in case of overcast or rainy weather, repeated spraying may be required.	It generally takes 2–3 h to take effect. Additionally, the spraying effect remains the same in rainy weather.
Clean process	Residual substances from the sodium metal method	The ammonia cyanidation method, which uses liquid ammonia, allows for gas recovery and does not produce waste.
Non-accumulative	It may remain in crops themselves, air, water sources, and soil, causing secondary or multiple hazards after accumulation.	It is impossible for it to accumulate in soil and air, or accumulate inside plants. It poses no secondary hazards to insects, animals, and humans.

Ethical analysis

Research ethics and original intentions in technology acquisition. During the initial stages of China's PQ research and development, the original international patents had expired, meaning that even if the original technology was imitated, there would be no misconduct such as plagiarism or theft. During the Ninth Five-Year Plan period, China began to emphasize environmental protection and imposed restrictions on the original sodium metal process. The most advanced aminocyanide process (also known as the liquid ammonia process) was only mastered by Syngenta UK. For China, this was a complete creation from scratch. During the research and development process, Shandong Institute actually faced a somewhat unfair scientific research environment. With the highest starting difficulty and international constraints, Shandong Institute adhered to the principle of scientific research integrity and ultimately broke through the bottleneck through cooperation with sibling institutions.

Furthermore, the original intention behind the development of this product was to improve the relatively backward situation of agricultural technology in China. At that time, most herbicides in China were imported, expensive, and subject to foreign control. In this context, as a large agricultural country, establishing an independent pesticide production and sales system was of great significance. After the successful development of PQ, prices dropped significantly, "from the price of ginseng to the price of cabbage," greatly benefiting farmers. From raw materials to final products, everything was controlled domestically, which had significant socio-economic benefits and industrial security value.

However, at that time, both domestically and internationally, there was insufficient understanding of the dangers of PQ, and there were few reports on it. The first case of PQ poisoning occurred in Ireland in 1964. In 1985, there was an incident in Japan where PQ was used for poisoning in a vending machine. Since these were isolated incidents, and the speed and scope of information dissemination were far less widespread than they are today in the 21st century, they did not even been taken into consideration of mainstream Chinese media at that time [8]. Therefore, Shandong Institute, as a research institution, did not have any deliberate motive to develop PQ for profit while knowingly harming the environment.

On the contrary, the research team had a high moral starting point. This was because after 1992, China's reform and opening-up entered a peak stage, with rural labor force migrating to urban areas in waves, making traditional labor-intensive manual weeding unsustainable. Therefore, the invention and improvement of easy-to-use herbicide categories were naturally the aspirations of farmers. Once the domestic production process was successfully developed, it greatly reduced farmers' costs for pesticides, which was a major benefit for both the country and the people.

Environmental ethics and outcomes in the production process. During the production process, research and development units worked closely with production units to push the process accuracy to its limits from the perspectives of improving efficiency and reducing environmental pollution. This included the following aspects: Firstly, the overall process adopted continuous operation throughout the entire workflow, with no interruptions in between. This significantly reduced time costs and completely eliminated the possibility of emitting intermediate products (which may be toxic). Secondly, the recovery and reuse of media were extremely high. Since liquid ammonia was used as an intermediate medium for the reaction, ultra-high pressure and ultra-low temperature conditions were set at the beginning of the reaction. After use, it could be recycled by further cooling and pressurizing. Since no harmful intermediates were produced in the process, there was no harm to the environment. Trace emissions could undergo ultimate treatment of the "three wastes" (waste water, waste gas, and solid waste), achieving almost zero waste and pollution. Finally, through the upgrade from pilot testing to mass production experiments, the above indicators were further optimized. Until now, the reaction capacity of PQ in a single reactor of 10 tons or more remains the highest in the domestic pesticide and chemical industry.

All raw materials, processes, and infrastructure required for production were domestically sourced. Among herbicides, China is the only developing country that has achieved a high degree of self-sufficiency; PQ is also the only pesticide product in China that ranks second in scale globally and is exported in large quantities to foreign countries.

From 2001 to 2011, China's PQ usage increased from 1,560 tons to 9,080 tons, with a compound annual growth rate of 19%, rapidly becoming one of the top herbicides. From 2011 to 2015, according to the "Special Research Report on China's Paraquat Market and Investment Directions (2011–2015)," national production reached 60,000 tons per year. Even after domestic sales were banned in 2016, China's share of exports continued to climb rapidly. According to the 2023 paraquat industry market analysis report, the global paraquat market size was 529 million yuan in 2022, with China supplying over 227 million yuan.

Comprehensive analysis (Part A)

We use intellectual orientation as the horizontal axis and ethical orientation as the vertical axis to create a coordinate system as shown in the figure below.

From the perspective of agricultural chemicals, PQ in China has followed such a path: it rapidly climbed from a position of high ethics and low intellectuality to one of high ethics and high intellectuality, namely Path a. It is worth noting here that neither Shandong Institute nor many production units followed Path b, which is the "pollute first, discharge later" approach (Figure 1). Instead, they positioned themselves highly at the outset, which is also the reason for their rapid market acceptance and continued brilliance in the international market after domestic restrictions.

As a lethal drug: paraquat in the midst of a public health crisis

Post-event control (ethical and intellectual analysis)

Around 2010, before "PQ" became a shocking news headline, relevant departments had already paid attention to it and taken corresponding measures.

The cases of PQ poisoning drew the attention of the nation. The research and production institutions of paraquat decided to jointly take measures. As early as 2011, Shandong Institute, together with 11 paraquat production enterprises such as Lvba, Red Sun, Syngenta, and Shandong Kexin, as well as emergency experts from Qilu Hospital, established the China Paraquat Manufacturers Product Management and Social Care Working Group (hereinafter referred to as the "Paraquat Social Care Working Group"). The father of Chinese paraquat, the head of drug research and development at Shandong Institute, and the heads of four PQ production enterprises served as deputy group leaders. By the end of 2012, the working group had raised more than 20 million yuan for training and promotion among emergency medical institutions in various provinces, printing and distributing standards free of charge, and establishing a 24/7 PQ assistance hotline (set up in Shandong and Sichuan). After July 2017, the working group was renamed the "China Pesticide Safety Social Care Working Group" and continued to provide assistance to society. The Social Care Working Group formulated a constitution and operated as a non-governmental organization, expanding from 13 institutions at its inception to more than 30.

The core focus was on rapid medical diagnosis and treatment protocols. Based on the "Qilu Protocol" (Qilufangan,) for paraquat poisoning treatment, Qilu Hospital of Shandong University conducted in-depth research on the latest clinical evidence, extensively consulted renowned domestic experts, and referred to relevant chapters on paraquat poisoning in the national textbooks "Emergency Medicine" and "Preventive Medicine" as well as the national standard "Diagnosis of Occupational Acute Paraquat Poisoning" (GBZ246-2013) to propose the "Taishan Expert Consensus" (Taishangongshi) on the diagnosis and treatment of paraquat poisoning for public comment. From November 1st to 3rd, 2013, the Third National Academic Conference on Paraquat Pesticide Poisoning was held in Jinan, Shandong Province, and the revised draft of the "Taishan Expert Consensus" on the diagnosis and treatment of PQ poisoning was approved by the conference [9, 10].

Its specific content includes the following: (1) The alveolar and interstitial fibrosis that appears in the late stages of PQ poisoning is called "PQ lung," which is a variant form of acute respiratory distress syndrome (ARDS). Paraquat is rarely degraded in the body and is often excreted in its original form through feces and urine, with a small amount excreted through breast milk. The lungs are the primary target organ, while the digestive system, urinary system, immune system, circulatory system, and nervous system are also target organs. Respiratory damage is the most prominent manifestation, and severe cases can rapidly develop lung edema and pneumonia within 1 to 3 days, leading to death from acute respiratory distress syndrome (ARDS) or multiple organ dysfunction syndrome (MODS) (Figure 2). Blood and urine samples should be tested for PQ, and it is important to note that samples should be stored in plastic tubes, not glass tubes. The concentration of PQ in blood and urine can be quantitatively determined using high-performance liquid chromatography (HPLC) or HPLC-mass spectrometry (HPLC-MS). (2) Treatment Methods. Those who have been exposed to a large amount of PQ should immediately leave the scene. In cases of skin contamination, the affected area should be rinsed with running water or soapy water for 15 min. In cases of eye contamination, the eyes should be rinsed with water for 10 min. For those who have ingested paraquat, vomiting should be induced and gastric lavage should be performed immediately, followed by whole gastrointestinal decontamination using the "White + Black Recipe". "White" refers to Smecta (Fuller's earth), and "Black" refers to activated charcoal. Specific method: Dissolve 30 g of Smecta in 250 mL of 20% mannitol and take it in divided doses. Dissolve 30 g of activated charcoal (powder) in 250 mL of 20% mannitol and take it in divided doses. The first dose should be completed within 2 h, and the subsequent doses can be taken in divided doses on the second day and thereafter. On the third and fourth days, halve the mannitol dose and dilute it with an appropriate amount of mineral water. In the absence of these medications, early oral administration of an appropriate amount of muddy water at the scene can help improve prognosis. Glucocorticoids are the primary treatment for paraquat poisoning. Early and adequate glucocorticoid therapy with methylprednisolone is preferred. Severe cases may receive pulse therapy with 500–1,000 mg of methylprednisolone daily for 3–5 days, followed by gradual dose reduction based on the patient's condition. At the same time, cyclophosphamide should be used rationally to prevent and treat late-stage lung fibrosis. Appropriate use of traditional Chinese medicine as adjuvant therapy is also recommended. Ultimately, a cure rate of 61–62% can be achieved.

Pre-control (ethical and intelligent analysis)

The three startling words "Bai-Cao-Ku" have already been tightly associated with "suicide (or poisoning) by drinking pesticides" [11]. However, focusing solely on post-control measures is far from sufficient. In fact, shortly after paraquat was launched onto the market, Shandong Institute of Pesticide Sciences embarked on a second technological breakthrough-namely pre-control, to prevent misuse by others (Table 2). Firstly, in terms of appearance design, the color was changed to dark green, and the packaging was made to look "ugly" as a warning to prevent misuse. The fonts and other elements were designed by medical psychology experts to avoid triggering suicidal tendencies. Secondly, an odorant was added to make it smell extremely nasty. Thirdly, an emetic was added, which acts on the central nervous system of the brain, causing vomiting within a very short period of time. Finally, research has shown that the time period for impulsive suicides to consider suicide is 13 seconds. Based on this, Shandong Institute changed the originally easy-to-drink liquid formulation into a granular formulation, and used tear-resistant water-soluble containers that can only be dissolved slowly in water, requiring a significant amount of time. This greatly reduces the possibility of impulsive suicides. The technical difficulty lies in the fact that paraquat is highly soluble in water, so the new technology requires the production workshop to achieve a cleanliness level of 0.01 ppm, which is the highest and only standard among similar industrial installations worldwide. Shandong Institute believes that any technological invention should promote social progress; if it poses a hazard, the inventor has an obligation to eliminate it, as it is a matter of "questioning conscience".

These efforts were recognized by the Ministry of Chemical Industry, and several new patent improvements led to the obtainment of production licenses for safer formulations. Unfortunately, the Ministry of Agriculture still insisted on the sales restriction order. Therefore, to date, PQ can only be exported and cannot be sold or used domestically in China.

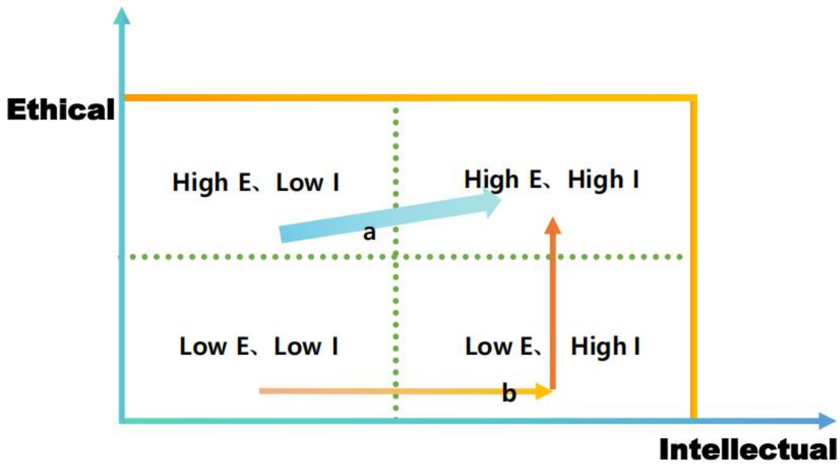

Figure 1 Ethical and intellectural analysis of paraquat as a chemical industrial product

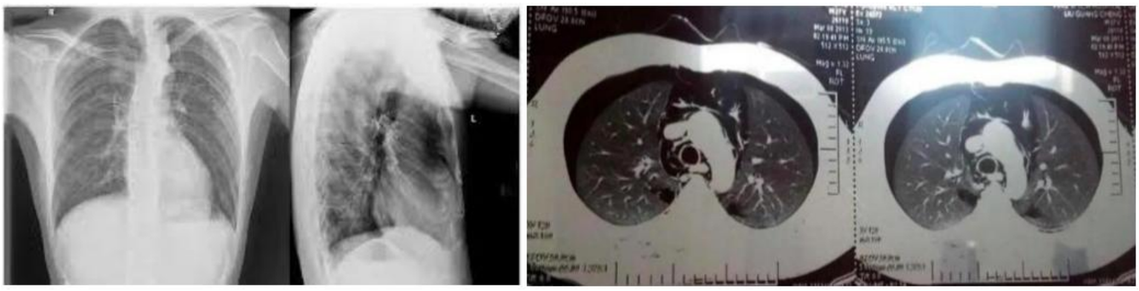

Figure 2 Lung condition of paraquat-poisoned patients

History and Philosophy of Medicine 2025;7(2):8. https://doi.org/10.53388/HPM2025008

Table 2 Paraquat poisoning prevention and assistance program: ethics-based actions by the supply side

	Improvement measures	Objectives
Develop safe formulations	Change the appearance color to dark green odor; Add an odorant taste; Add an emetic packaging; Tear-resistant time consumption; Change from ready-to-use aqueous solution to granular form.	Prevent misuse obstruct intentional ingestion assist in first aid support
Establish a social care working group	Distribution of brochures; Free distribution training in first aid techniques; Qilu program setting up a rescue hotline; with more than 4 professionals on standby round-the-clock; Other assistance.	Enhance vigilance enhance the public's correct cognition strive for valuable rescue time greatly save lives

Comprehensive analysis (Part B)

After the 2016 ban, PQ poisoning incidents continued to occur, causing widespread fear among the people. This was mainly due to the residual pesticides left in farmers' homes (including some agricultural material supply institutions), which still posed a potential hazard.

From the perspective of intervention products in public health crises, PQ in China has followed such a path, starting from "high ethics-low intelligence," and despite the efforts of multiple parties (including enterprises, pesticide research and development institutions, and hospitals), it has still not escaped the scope of "high ethics-low intelligence" (Figure 3). From the perspective of implementation effects, the maximum effectiveness of a cure rate exceeding 60% and a 24-h hotline response under the circumstances of restrictions, if paraquat were to be used freely, would still face tremendous difficulties in addressing public crises.

In terms of suicides, they can be divided into deliberate and impulsive types based on their behavior, and further categorized into absolute and relative types based on the methods used. Drinking pesticide to commit suicide, compared to other forms of poisoning, is to a certain extent a demonstration of social disputes or an impulsive act of self-harm. This is because if timely treatment is provided after pesticide poisoning, there is no risk to life, and the related social conflicts can be somewhat alleviated. Of course, there are also cases of deliberate pesticide ingestion, but these individuals usually opt for absolute methods such as overdosing on sleeping pills or ingesting tetramethylene disulfotetramine. These types of drugs are generally subject to strict control. Under strict control, if a suicide attempt is still carried out using these methods, the associated parties (such as a store selling ropes or a construction company building tall buildings) are generally exempt from liability.

From the perspective of social issues, the situation of suicidal patients (patients who ingest poison) is also changing, shifting from primarily accidental ingestion to the emergence of the "determined to die" type (represented by triangles in Figure 4). There are cases where individuals specifically wait for insoluble solid paraquat to dissolve before ingesting it. In past poisoning cases, there were indeed individuals who spent hours patiently waiting for solid paraquat to slowly dissolve before committing suicide. In such situations, paraquat still bears social responsibility.

The result of focusing on post-event control rather than pre-event control is that the solution to the problem remains at a stage of high ethics but low intelligence (Path c–d). Ultimately, paraquat had to be withdrawn from the Chinese market.

Finding 1: Even with a high level of professional ethics, incidents that harm social interests may still occur. And a product may face social responsibility due to misuse in non-target areas.

Through a full life cycle analysis, we have found that the subsequent ban on paraquat was not caused by deliberate intent in its research and development, production, sales, or use, nor was it due to social tolerance of technical limitations (knowingly initiating something harmful). This phenomenon occurs in compliance with business norms, without any improper negligence, and even with benign motives in subsequent remedial actions. However, the outcome is severe sanctions. This is referred to in this paper as "non-liability paradox."

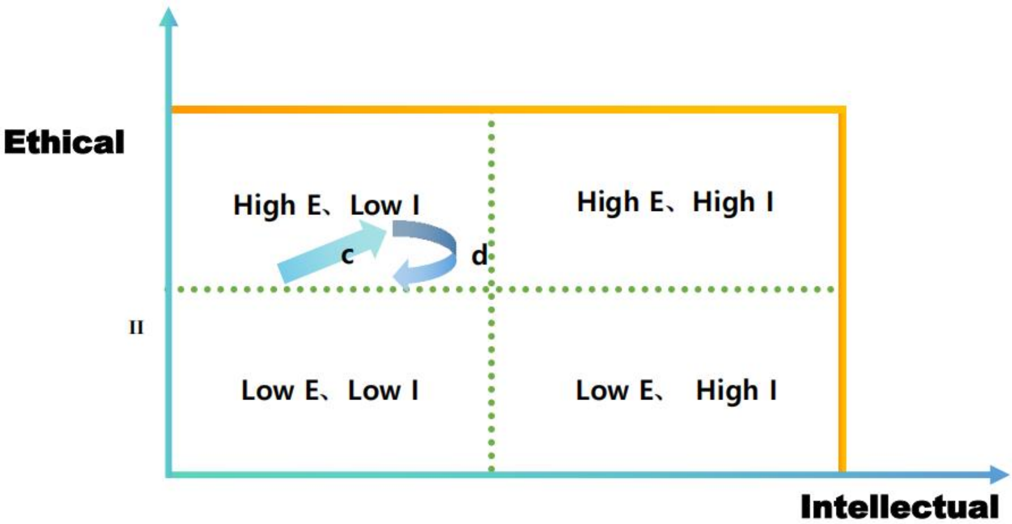

Figure 3 Ethical and intellectual analysis of paraquat as a toxic agent

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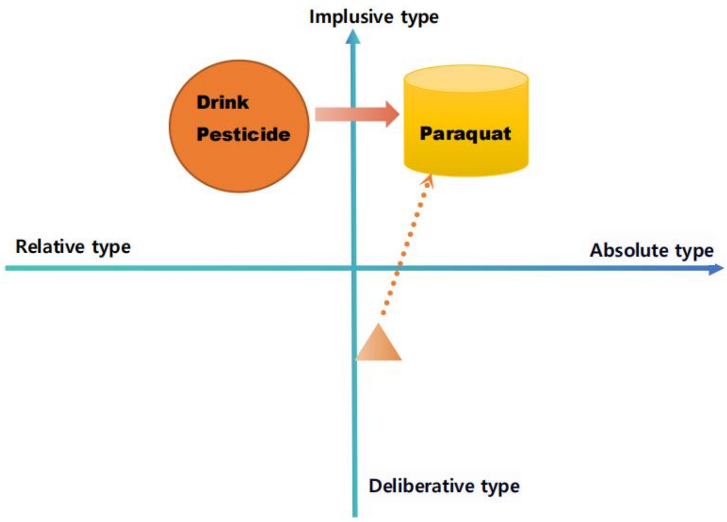

Figure 4 Schematic diagram of paraquat misuse behavior actors

How to solve the problem of paraquat as a mixed entity?

Here, the questions to be raised are-why are developed countries such as the United States and Japan still using paraquat? Why can they solve the same problems that we face? And, is there a fundamental solution to this type of problem for humanity?

Experiences of developed countries: different production models. Apart from China, over 100 countries worldwide continue to produce and use PQ, including the United States and Japan. So, have the relevant departments in these countries failed to fulfill or even ignored their social responsibilities? No. The answer may lie in the relatively low number of poisoning cases. Besides the large population base in China, the relevant institutional development in developed countries is worth learning from.

Taking the United States as an example, its pesticide registration and use system is very strict (Figure 5). The US registration system includes three stages: pesticide registration, pesticide reregistration, and pesticide registration review. Pesticides must obtain registration permits from both the federal Environmental Protection Agency (EPA) and the local state government's agriculture department before they can be sold and used. In terms of pesticide use, the US has distinct characteristics in pesticide applicators, application equipment, and organizational methods. For the management of pesticide applicators, the US requires that restricted pesticide users must undergo training at state universities, pass state government exams, and obtain a use permit issued by the state government before they can operate. Some states also require that after obtaining the use permit, applicants must undergo two seasons of practical operation before obtaining a use license. The license is generally valid for three years and must be renewed through training and exams. Growers must submit an application to the county agricultural inspector through the online system 24 h before application, reporting the location, area, crops, control targets, pesticide types, etc., and can only be implemented by professional licensed personnel after approval. Detailed usage records must be kept, and warning signs must be set up at the application site. Large self-propelled boom sprayers are commonly used for field crops, with spray widths reaching 24–36 meters. Agricultural aviation projects are widely used for seeding, fertilizing, weeding, and pest control, accounting for 40% of the annual cultivated land area treated in the US. Vendors, manufacturers, and licensed applicators who violate the regulations will be fined 1,000 to 50,000 and imprisoned for 30 days to 1 year [12].

In terms of pesticide registration, China implemented the "Pesticide Registration Data" regulation in 2008, which made preliminary provisions. However, it was only after the paraquat ban that a relatively complete pesticide registration management system was established. In 2017, the State Council issued the new "Pesticide Management Regulations (2017)". In the same year, the Ministry of Agriculture issued a series of laws and regulations, including the "Measures for the Administration of Pesticide Registration (2017)", "Measures for the Administration of Pesticide Production Licenses (2017)", "Measures for the Administration of Pesticide Business Licenses (2017)", "Measures for the Administration of Pesticide Registration Experiments (2017)", "Measures for the Administration of Pesticide Labels and Instructions (2017)", and "Regulations on the Registration Approval and Management of Pesticide Names (2017)" [13].

In terms of pesticide application, there is still a significant gap in specific application supervision and pesticide consultation management. However, this is also related to the predominantly fragmented distribution of cultivated land in China, making it difficult to directly adopt the experiences of developed countries. At the end of 2013, the average land management scale of farmers in China was only 0.65 hectares, divided into 5.1 plots, exhibiting obvious characteristics of small-scale decentralized management and land fragmentation. To this day, 96.1% of farmers in China still manage farmland under 2 hectares, with a total of 255 million farm households. Pesticide application mainly adopts manual and semi-mechanized decentralized methods, lacking precise management [14].

In terms of product sales control, in principle, the nine domestic enterprises with production licenses had the right to sell before the ban was issued. During the transition from pesticide production to application, it mainly relied on the agricultural material distribution system formed since the founding of the People's Republic of China-a scattered distribution channel characterized by "wholesale-retail" and relying on state-owned and private agencies. Its advantages include low costs and adaptability to rural conditions; however, its disadvantages include the complete lack of registration and recording of farmers' specific information, the specific plots where pesticides are applied, crop types, application rates, and effects. It is even unclear whether the pesticides are used at all, as farmers have the habit of retaining leftover pesticides for use in the following year. The recycling and disposal of used pesticide bottles are even more chaotic and mostly unmanaged.

Therefore, pesticide application technology itself is closely related to the agricultural production mode of a country (Figure 6). Even after China's reform and opening-up, although a large number of advanced technologies have been adopted and upgraded, the main characteristics of farmland fragmentation, topographical relief, mixed crop types, and fragmented property rights (land use rights) have not changed. Consequently, China cannot imitate the management experience of developed countries such as the United States in pesticide management. Therefore, the social issues caused by suicide through the misuse of PQ differ significantly from those in developed countries at this level. This is also the reason why the United States, Japan, and other countries can continue to use it under good management (operated by professionals). If the characteristics of large-scale decentralized use by Chinese farmers do not change for a considerable period, and the overall agricultural production mode and pesticide application mode remain mismatched, then it will be extremely difficult to reintroduce paraquat in China [15].

Individual technological innovations, even if locally perfect, may still conflict with the overall economy-the prevailing technological-economic paradigm of a country. The cost of the latter's change is enormous and may even have a deep cultural paradigm foundation. Diverse technological-economic paradigms may produce different ethical adaptation outcomes when facing the same individual technological innovation: varying degrees of conflict or harmony. In the case of conflict, the technological innovation may be temporarily halted or, alternatively, used as an opportunity to drive the replacement of a new technological-economic paradigm.

Finding 2: When advancing technological innovation, it is not sufficient to focus solely on the technology itself; improvements in the supporting management system are also necessary. In other words, technological development requires coordination within the overall paradigm. In future enterprise innovation, from conception to implementation, individual technological innovations must be coordinated with the overall technological-economic paradigm. This coordination can be achieved through "imaginative construction" before innovation to embed it into the existing paradigm, or it may involve paying immense costs to disrupt the existing technological-economic paradigm, thereby facilitating a higher balance of economic, social, and ecological benefits within a new technological-economic paradigm.

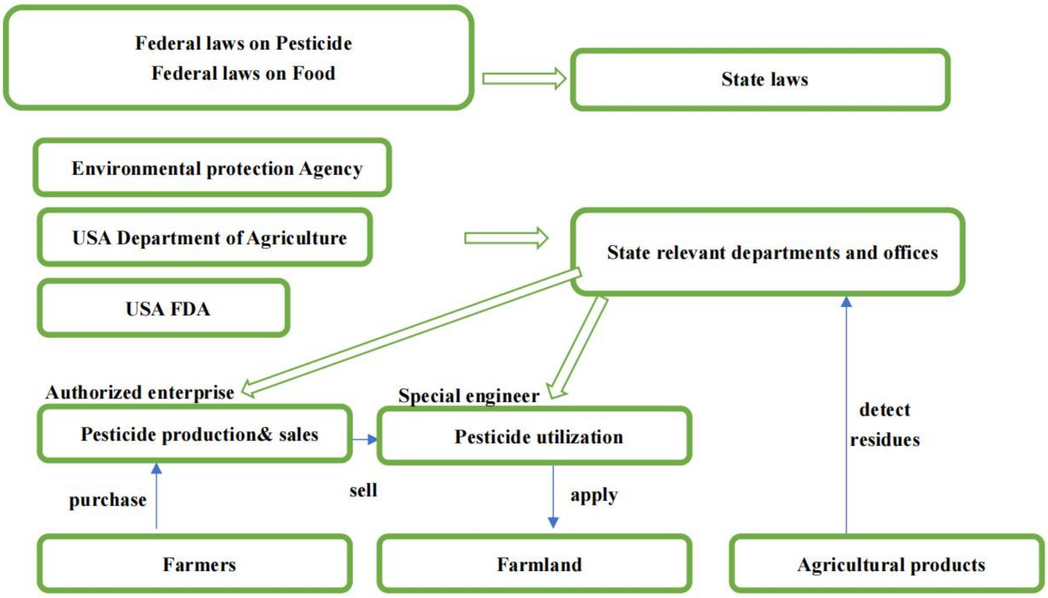

Figure 5 Schematic diagram of analysis on U.S. pesticide use management laws and enforcement agencies

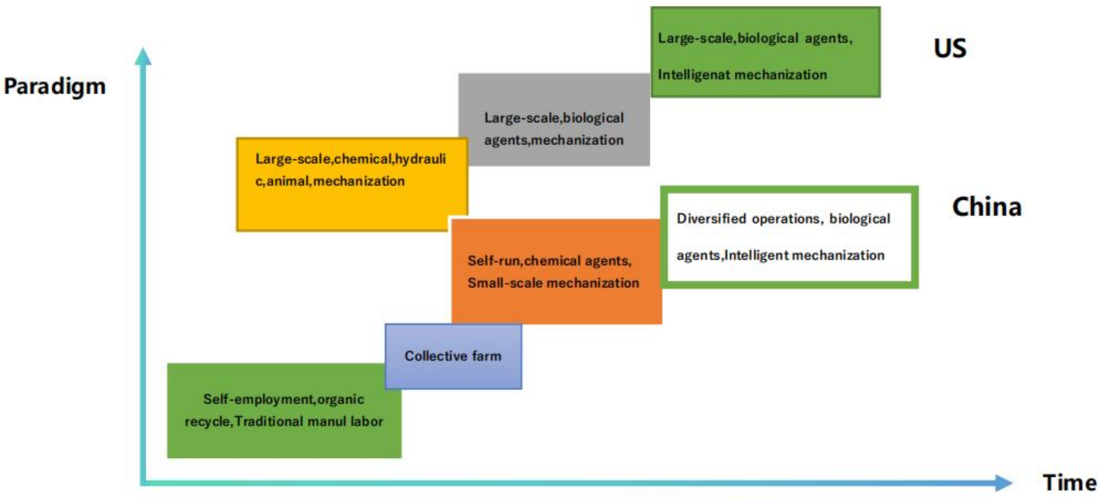

Figure 6 Pesticide application and agricultural production methods in China and the United States

The pesticide paraquat has encountered the dilemma of a "sales ban," which seemingly relates to a sudden change in the scope of stakeholders. The emergence of paraquat is due to its presence in a special category-its extremely high lethality makes it an absolute poison. For the families of impulsive suicides, or even the suicides themselves (those who survive temporarily after rescue), the extreme toxicity of this "pesticide" is unacceptable. Many of those who misuse it do so out of a moment of despair or merely to "frighten their loved ones," but ultimately face a "hopeless" outcome [16]. This has led to the emergence of new stakeholders such as suicide groups, families of suicides, hospitals and rescue units, and spontaneously formed corporate and enterprise joint rescue organizations. The accessibility, low-dose high toxicity, and extreme lethality of paraquat pose a threat to this new stakeholder group. In the context of the principle that life takes precedence, PQ's status as an auxiliary in agricultural production is insufficient to counteract these concerns, ultimately leading to its ban [17].

Conversely, the dilemma faced by PQ has a certain degree of inevitability.

Historically, many chemicals have later been found to have non-degradable and cumulative toxic effects, leading humans to eventually abandon their use due to the unbearable burden. For example, DDT, mentioned earlier, was ultimately abandoned as a pesticide. Another example is the white plastic bag, invented by Max Schuschny in 1902 and still in use today, for which humans have yet to find a suitable solution. We can only move forward with the problem, as white pollution continues to worsen day by day. This paper argues that new products, especially new chemical products, regardless of their application scenarios, should undergo long-term clinical trials similar to those for pharmaceuticals before being mass-produced to avoid subsequent harm. From the perspective of knowledge management, the innovation ecosystem needs to incorporate a knowledge subsystem for "human-centered development" (Figure 7) [18]. Moreover, medical experts should be involved in product development from the early stages, rather than appearing only at the final stage (Table 3). In a sense, this is akin to treating "illnesses before they occur". This will greatly prevent unforeseen disasters from happening and is more effective and economical compared to subsequent remedial measures, as many belated efforts are unable to solve these problems [19].

Finding 3: In the field of chemical products, as well as many other new product areas, developing with a "polarized" mindset, despite achieving breakthroughs in certain indicators, may cause systemic harm.

For example, genetically modified organisms (GMOs) and nuclear technology are both technologies that exhibit polarization. The drawback of these new technologies is that if they are expanded on a large scale without corresponding restraint technologies in place, they may bring irreversible harm. Therefore, in future technological innovation, as researchers, when developing a new technology Alpha, one should also focus on developing its reverse technology A −. Alternatively, when applying the new technology Alpha in practice, one could use Alpha + Beta together, and add Gamma in case of harm, so that Beta + Gamma = Negative Alpha, achieving a hedging effect.

Table 3 Examination of paraquat: in a full process-all stakeholders paradigm

	Enterprise	Individual/Society	Government	Healthcare sector
Project initiation and creativity	Initiative/Non-intentional Act	——	Support	Failure to participate
Research and development/Production	Active/Passive Stop	——	Support/Prohibit When necessary	——
Sales/Utilization	Active/Passive Stop	Not fully considered	Support/Prohibit When necessary	——
Volunteer rescue	Active participation	No obvious participation	Appeal and Guide	Proactive rescue

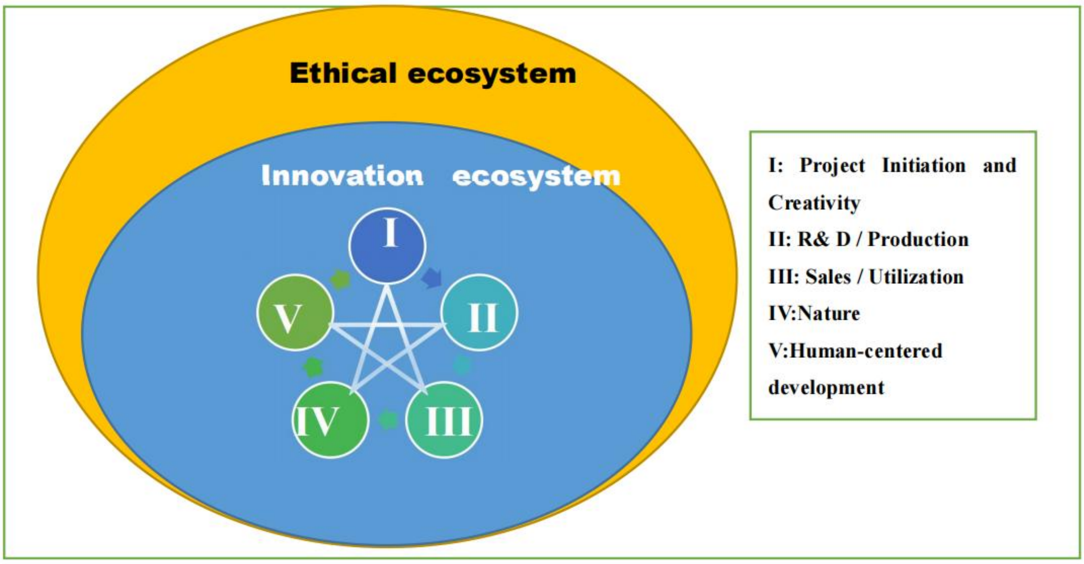

Figure 7 The "human-centered development" subsystem within the innovation ecosystem-ethical ecosystem

Conclusion

To put it bluntly, the development of PQ in China is a comprehensive event and a serious proposition.

As an agricultural chemical, its technology is absolutely leading, and even the entire process meets environmental and sustainable ecological standards. However, as discussed earlier, it represents a discordant note in China's integration into the global industrial revolution. Merely developing technology alone is insufficient; there is also a need to synchronize upgrades and learn and innovate in technological governance approaches.

As an intervention in public crises, both medical departments and enterprises have made sufficient efforts and achieved considerable accomplishments. However, the best approach is to prevent problems before they occur. That is, when new chemical products are introduced to the public, their degradation products and neutralizing agents should be studied, and medical experts should be involved early on, rather than waiting for problems to arise.

This paper believes that post-event remediation is inferior to pre-event control, and research based on high ethics and high intelligence requires the support of a scientific and technological governance system [20]. China is currently in a critical period of transition from industrial civilization to ecological civilization. Science and technology, as the cornerstone of great power development, require a focus on comprehensiveness and forward-looking in every innovation, considering the supreme overall interest and meeting the stringent requirements of taking the big picture into account. Pharmaceutical services and psychological assistance services in emergency situations should serve as supplements, not the norm. A technology-oriented approach and layout aimed at preventing problems before they occur will become and must become the key and hub of China's comprehensive development.

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