



EMPTY PESTICIDE CONTAINERS REVIEW

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Abstract. The increasing use of pesticides in modern agriculture has resulted in the generation of large amounts of hazardous waste, particularly in the form of empty pesticide containers (EPC). Improper management of these containers poses significant risks to human health and the environment. This study presents a systematic literature review of EPC management, based on 17 peer-reviewed articles retrieved from the Web of Science and Scopus databases, covering the period 2000–2025. The review analyzes research trends, methodological approaches, and thematic focus areas within the existing literature. The findings reveal a strong dominance of behavioral studies, which account for more than half of the publications, primarily focusing on farmers' disposal practices, awareness, and reuse behavior. In contrast, technical, logistical, and policy-oriented studies remain limited, highlighting significant research gaps. The results also indicate a sharp increase in publications after 2020, suggesting growing global attention to EPC management within the context of sustainability and circular economy. The study concludes that more integrated, interdisciplinary research is needed, particularly in the areas of governance, system design, and environmental risk assessment, to support the development of effective and sustainable solutions for pesticide container management.

Keywords: empty pesticide containers; literature review

Аннотация. Рост использования пестицидов в современном сельском хозяйстве привёл к образованию значительных объёмов опасных отходов, особенно в форме пустых контейнеров из-под пестицидов (EPC). Ненадлежащее обращение с такими контейнерами представляет серьёзную угрозу для здоровья человека и окружающей среды. В данном исследовании представлен систематический обзор литературы по управлению пустыми контейнерами из-под пестицидов, основанный на анализе 17 рецензируемых статей, извлечённых из баз данных Web of Science и Scopus, опубликованных в период 2000–2025 гг.

Обзор направлен на анализ исследовательских тенденций, методологических подходов и основных тематических направлений существующей литературы. Результаты показывают доминирование поведенческих исследований, на долю которых приходится более половины



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публикаций, и которые в основном посвящены практике утилизации контейнеров фермерами, уровню осведомлённости и повторному использованию. В то же время исследования, посвящённые техническим, логистическим и институциональным аспектам, остаются ограниченными, что указывает на наличие значительных пробелов в научных знаниях.

Кроме того, выявлен значительный рост числа публикаций после 2020 года, что свидетельствует о возрастающем глобальном внимании к проблеме управления контейнерами из-под пестицидов в контексте устойчивого развития и циркулярной экономики. В работе делается вывод о необходимости проведения более интегрированных и междисциплинарных исследований, особенно в области управления, разработки систем и оценки экологических рисков, для обеспечения эффективных и устойчивых решений в сфере обращения с пестицидными контейнерами.

Ключевые слова: пустые контейнеры из-под пестицидов, обзор литературы;

Annotatsiya. Zamonaviy qishloq xo'jaligida pestitsidlar qo'llanilishining ortishi natijasida xavfli chiqindilar hajmi sezilarli darajada ko'paydi, ayniqsa pestitsidlar uchun ishlatilgan bo'sh idishlar shaklida bu holat ahamiyat kasb etmoqda. Ushbu idishlarni noto'g'ri boshqarish inson salomatligi va atrof-muhit uchun jiddiy xavf tug'diradi. Mazkur tadqiqotda pestitsid idishlarini boshqarish bo'yicha tizimli adabiyotlar sharhi taqdim etilgan bo'lib, u Web of Science va Scopus ma'lumotlar bazalaridan olingan 2000–2025 yillar oralig'ida chop etilgan 17 ta ilmiy maqolaga asoslangan.

Mazkur sharh mavjud adabiyotlardagi tadqiqot yo'nalishlari, metodologik yondashuvlar va asosiy tematik yo'nalishlarni tahlil qiladi. Natijalar shuni ko'rsatadiki, nashrlarning yarmidan ko'pi fermerlarning pestitsid idishlaridan keyingi muomalasi, xabardorlik darajasi va qayta foydalanish xatti-harakatlariga bag'ishlangan bo'lib, xulq-atvor tadqiqotlari ustunlik qiladi. Shu bilan birga, texnik, logistika va siyosatga oid tadqiqotlar yetarli darajada rivojlanmagan bo'lib, bu ilmiy bo'shliqlar mavjudligini ko'rsatadi.

Shuningdek, 2020-yildan keyingi davrda nashrlar sonining keskin oshgani aniqlangan bo'lib, bu pestitsid idishlarini boshqarish muammolariga barqaror rivojlanish va sirkulyar iqtisodiyot doirasida global e'tibor ortib borayotganini ko'rsatadi. Tadqiqot yakunida pestitsid idishlarini samarali va barqaror boshqarish uchun, ayniqsa boshqaruv tizimlari, tizimli yechimlar va ekologik xavflarni baholash sohalarida yanada integratsiyalashgan va fanlararo tadqiqotlar zarurligi ta'kidlangan.

Kalit so'zlar. bo'sh pestitsid idishlari, adabiyotlar sharhi

INTRODUCTION

The intensification of agricultural production has led to a substantial increase in pesticide use worldwide. While pesticides play a crucial role in enhancing crop





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yields and ensuring food security, their application generates significant quantities of hazardous waste, particularly in the form of empty pesticide containers (EPC). These containers often retain residues of toxic chemicals and, if improperly handled, pose serious risks to both human health and the environment [1, 2, 4].

In many regions, especially in developing and transition economies, the management of empty pesticide containers remains inadequate. Farmers frequently dispose of these containers through unsafe practices such as open burning, burying in fields, or discarding them in irrigation canals and water bodies [8, 2]. In some cases, containers are reused for domestic purposes, including storing food, water, or fuel, which significantly increases the risk of direct human exposure to toxic substances [10]. These practices can result in soil and water contamination, long-term environmental degradation, and adverse health impacts on rural populations.

To mitigate these risks, several safe management strategies have been promoted, including triple rinsing, proper collection systems, and recycling schemes [7]. In addition, policy instruments such as Extended Producer Responsibility (EPR) and reverse logistics systems have been introduced in several countries to improve the collection and safe disposal of pesticide containers [9, 5]. Despite these efforts, adoption remains uneven due to factors such as limited awareness, insufficient infrastructure, weak institutional frameworks, and lack of enforcement mechanisms [12, 3].

Although there is a substantial body of research on pesticide use and environmental impacts, studies specifically addressing empty pesticide container management remain relatively limited and fragmented. Existing literature is largely dominated by studies on farmer behavior and disposal practices, while comparatively less attention has been given to technical, logistical, and governance aspects [6, 11]. This imbalance highlights the need for a more comprehensive and structured assessment of the current state of knowledge.

Therefore, the objective of this study is to systematically review scientific literature on the management of empty pesticide containers. Using publications indexed in the Web of Science and Scopus databases, this study analyzes 17 peer-reviewed articles published between 2000 and 2025. The review aims to (i) classify existing research into key thematic categories, (ii) examine the methodological approaches used in the literature, and (iii) identify critical gaps in current research. By providing a structured synthesis of existing studies, this research contributes to a better understanding of EPC management and supports the development of more effective and sustainable solutions.

The remainder of the paper is structured as follows. The next section describes the research methodology, followed by a presentation of the research findings. Finally, the paper concludes with a summary of the main results.



MATERIALS AND METHODS

This study adopts a systematic literature review approach to analyze existing research on empty pesticide container (EPC) management. The literature search was conducted using two major academic databases, namely Web of Science (WoS) and Scopus, which are widely recognized for their comprehensive coverage of peer-reviewed scientific publications.

The search strategy was designed to identify studies related to the management, disposal, recycling, and handling of empty pesticide containers. Keywords used in the search process included “*empty pesticide containers*”, “*pesticide container disposal*”, “*pesticide packaging waste*”, and “*pesticide container management*”.

To ensure the quality and relevance of the selected studies, several inclusion and exclusion criteria were applied. Only peer-reviewed journal articles indexed in Web of Science and Scopus were considered. The time frame for the review was limited to publications from 2000 to 2025, allowing for an analysis of research trends over a 25-year period. Studies were included if they explicitly addressed issues related to empty pesticide containers, including disposal practices, recycling, reuse, or management systems. Publications such as conference proceedings, reports, and other forms of grey literature were excluded, as were studies focusing solely on pesticide toxicity without reference to container management.

The selection process involved three stages. First, titles were screened to identify potentially relevant studies. Second, abstracts were reviewed to assess their relevance to the topic. Finally, full-text screening was conducted to confirm eligibility based on the defined criteria. After this multi-stage screening process, a total of 17 relevant articles were selected for detailed analysis.

For each selected study, key information was extracted, including authorship, publication year, geographical focus, research methods, research type (quantitative, qualitative, or mixed), as well as the main objectives and findings. The selected papers were then systematically analyzed and categorized into thematic groups, such as behavioral studies, technical and environmental analyses, reverse logistics and system optimization, policy and governance, and review studies. This categorization enabled a structured comparison of research trends and facilitated the identification of key gaps in the existing literature.

Despite focusing on high-quality indexed databases, this study has certain limitations. The use of specific keywords may have excluded relevant studies that address the issue indirectly using different terminology. In addition, the exclusion of grey literature may limit the representation of practical initiatives and policy reports. Nevertheless, the selected dataset provides a robust and reliable overview of the current state of research on empty pesticide container management. Now we turn to the findings.



RESULTS AND DISCUSSION

The study is based on 17 peer-reviewed articles retrieved from the Scopus and Web of Science databases. The literature search targeted studies specifically addressing the management of empty pesticide containers

The figure presents the distribution of the 17 selected studies over time (2002–2025) and clearly shows a strong upward trend in recent years (Figure 1).

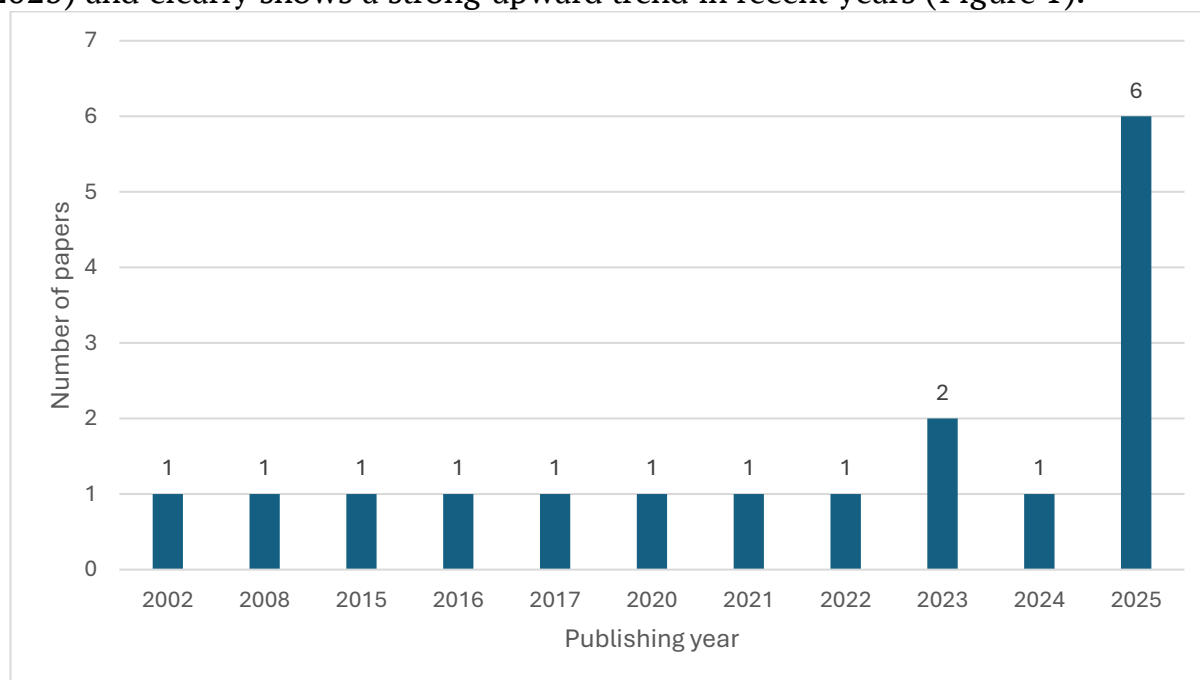


Figure 1. Publication period

The early period (2002–2017) is characterized by very sparse research activity, with only one paper published in each of the listed years. This indicates that research on empty pesticide container management was highly limited and fragmented during this period, with no clear continuous development or sustained academic attention.

A gradual transition phase appears between 2020 and 2022, where publications begin to emerge more regularly, although still at a low level (one paper per year). This suggests the beginning of increased recognition of the importance of the topic, likely linked to growing concerns about environmental sustainability and agricultural waste management.

The review of 17 studies shows that research on empty pesticide container (EPC) management is dominated by behavioral studies, mainly focusing on farmers' disposal practices, awareness, and reuse. Findings indicate that improper disposal, such as burning, dumping, and reuse, is widespread, particularly in developing countries (

Table 1). Technical research demonstrates that methods like triple rinsing can significantly reduce contamination levels, while logistics studies highlight the importance of efficient collection systems. However, policy and governance aspects remain underdeveloped, despite their importance for effective management. Overall,



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the literature reveals clear gaps in technical, system-level, and institutional research, although interest in EPC management has increased significantly in recent years.

Table 1.

Summary of literature review

No	Authors	Location	Method	Objective	Key findings
1	Huici et al. 2017	Bolivia	Survey	Assess EPC practices	Improper disposal high; training improved outcomes
2	Damalas et al. (2008)	Greece	Survey	Disposal practices	Unsafe disposal widespread
3	Mekonnen & Agonafir (2002)	Ethiopia	Survey	Handling practices	Unsafe reuse common
4	Karasali et al. (2015)	Greece	Lab experiment	Triple rinsing	Residues <0.1%
5	Mello & Scapini (2016)	Brazil	Case study	Reverse logistics	Improves environmental outcomes
6	Sorichetti et al. (2024)	Argentina	Optimization model	Logistics system design	Reduces cost and environmental impact
7	Silva-Rodríguez & Ocampo-Velez (2023)	Latin America	Modelling study	Logistics optimization	Improves collection efficiency
8	Handayani et al. (2025)	Global	System design	Governance	EPR critical
9	Mulugeta et al. (2025)	Ethiopia	Cross-sectional survey	Reuse behavior	68% reuse; low awareness
10	Yami et al. (2025)	Nigeria	Survey	Disposal behavior	Burning and reuse common
11	Karasmanaki et al. (2021)	Greece	Survey	Behavior analysis	Awareness insufficient
12	Mustafa et al. (2025)	Global	Review	EPC practices	Unsafe disposal dominant
13	Latt et al. (2023)	Global	Review	Disposal practices	Dumping and burning common
14	Papadimitriou et al. (2025)	Global	Review	Residue risks	Containers release pollutants
15	Yan et al. (2025)	China	SEM model	Behavioral drivers	Social norms influence recycling
16	Li et al. (2025)	China	Survey	Waste practices	Infrastructure limits recycling
17	Ding et al. (2025)	China	Survey	Recycling adoption	~42% participation

The distribution of research methods shows a strong dominance of quantitative approaches (64.7%), while qualitative (23.5%) and mixed-method (11.8%) studies remain limited. This indicates that research on empty pesticide container



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management is primarily focused on measuring behavior and technical outcomes, with insufficient attention to integrated and systemic analyses (Figure 2).

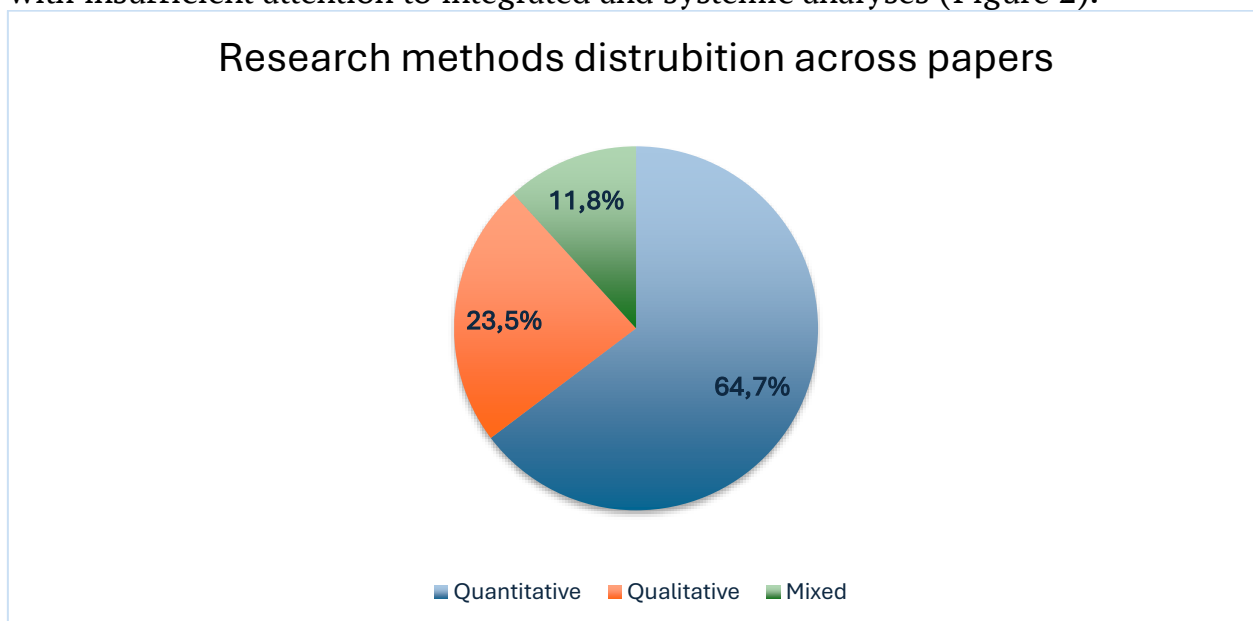


Figure 2. Research methods

The figure illustrates the distribution of research themes across the selected studies and reveals a strong imbalance in the focus of existing literature (Figure 3).

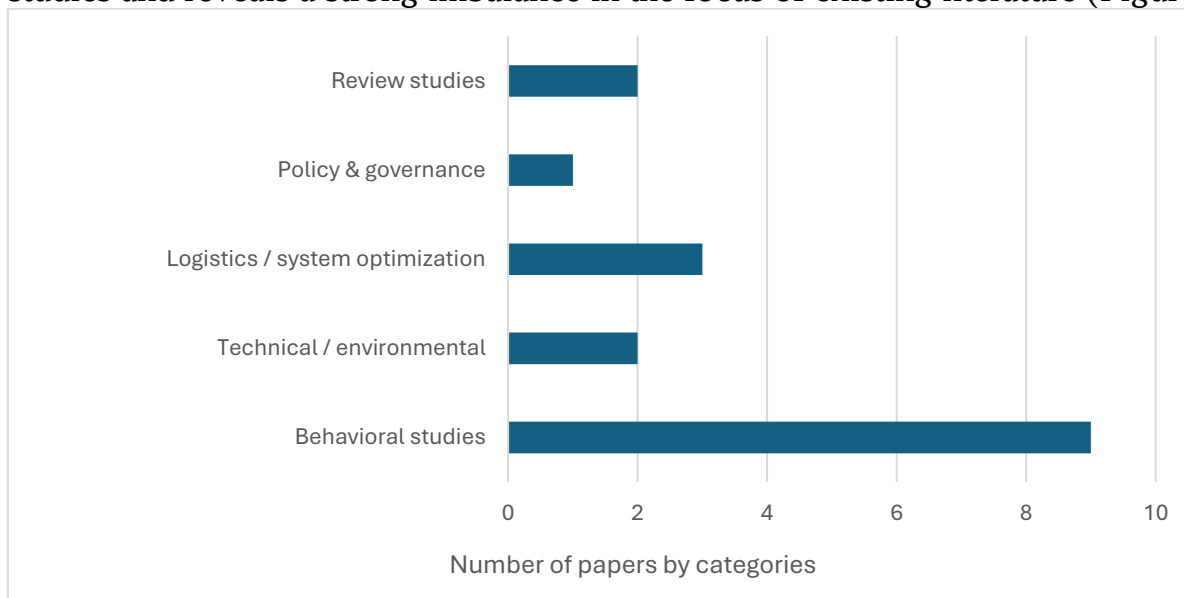


Figure 3. Papers by categories

The most striking feature is the dominance of behavioral studies, which account for the largest share (9 out of 17 papers). This indicates that the majority of research has concentrated on understanding how farmers handle empty pesticide containers, including disposal practices, reuse behavior, and awareness levels. This strong emphasis suggests that researchers perceive human behavior as the primary driver



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of improper container management, and efforts have largely been directed toward identifying behavioral barriers and promoting safer practices.

In contrast, logistics and system optimization studies (3 papers) represent a smaller but growing research area. These studies focus on designing and improving collection systems, reverse logistics, and recycling mechanisms. Their presence reflects an emerging shift toward system-level solutions, particularly within the context of circular economy approaches. However, their relatively low number indicates that such practical implementation frameworks are still underdeveloped.

The technical and environmental category (2 papers) is surprisingly limited. Given the importance of pesticide residues and environmental contamination risks, the small number of studies suggests that scientific evidence on the environmental impacts of empty containers is insufficient. This gap highlights the need for more laboratory and field-based research on contamination pathways, long-term impacts, and effectiveness of decontamination methods.

Similarly, review studies (2 papers) are few, indicating that the field lacks comprehensive synthesis and integration of existing knowledge. This limits the development of a coherent and consolidated research agenda and makes it more difficult to generalize findings across regions.

The most critical gap is observed in policy and governance research (only 1 paper). Despite the importance of regulation, institutional frameworks, and Extended Producer Responsibility (EPR) systems for managing pesticide container waste, this area remains significantly underexplored. This imbalance suggests that institutional and policy dimensions have not yet received sufficient scientific attention, even though they are essential for scaling up solutions.

CONCLUSION

This study reviewed 17 peer-reviewed articles on empty pesticide container management published between 2000 and 2025, using data from the Web of Science and Scopus databases. The results indicate that research in this field has increased significantly in recent years, particularly after 2020, reflecting growing awareness of the environmental and health risks associated with improper container disposal.

The findings show that the existing literature is heavily concentrated on behavioral studies, emphasizing farmers' practices, awareness, and disposal behavior. While these studies provide important insights into the human dimension of the problem, other critical areas remain underexplored. In particular, there is a limited number of studies addressing technical issues such as residue contamination, as well as system-level approaches including reverse logistics and recycling infrastructure. Most notably, policy and governance aspects, including regulatory frameworks and institutional mechanisms such as Extended Producer Responsibility, are significantly underrepresented.

These gaps highlight the need for a more balanced and integrated research agenda that combines behavioral, technical, and institutional perspectives. Future



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research should focus on developing comprehensive management systems that incorporate effective collection, recycling, and policy mechanisms. Additionally, more studies are needed in under-researched regions, including Central Asia, to better understand local challenges and design context-specific solutions.

Overall, this study provides a structured overview of the current state of research on empty pesticide container management and identifies key areas for future investigation, contributing to the development of more sustainable agricultural waste management practices.

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