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Dr. Hannah Krüger
Department of Environmental Sciences, Humboldt College, Berlin, Germany

Lukas Steinbach
Department of Food Chemistry, Munich Technical College, Munich, Germany

Dr. Emilia Vogt
Department of Agricultural Biotechnology, Cologne College of Applied Sciences, Cologne, Germany

Corresponding Author:
Dr. Hannah Krüger
Department of Environmental Sciences, Humboldt College, Berlin, Germany

Exploring household pesticide use and its impact on food safety: A study on resistance mechanisms

Hannah Krüger, Lukas Steinbach and Emilia Vogt

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Abstract
Household pesticide use has become a common practice in many regions as families seek to protect their food and living spaces from insects and other pests. While this practice is often perceived as necessary for ensuring cleanliness and preventing crop damage in small home gardens, it carries hidden risks for food safety and long-term public health. This study explores the patterns of household pesticide use and evaluates how these practices contribute to pesticide residues in food and the development of resistance mechanisms in common pests. A mixed methodological approach was employed, combining household surveys, laboratory testing of food samples for residues, and bioassays of pest populations to assess levels of tolerance. The results indicate that most households rely heavily on organophosphates and pyrethroids without observing safety intervals, leading to residues on vegetables and fruits that often exceed recommended safety thresholds. In parallel, resistance mechanisms, particularly metabolic detoxification and target-site mutations, were detected in household pest populations, raising concerns about reduced effectiveness of widely used chemicals. The findings highlight an urgent need to raise awareness among households regarding safe handling of pesticides, to encourage integrated pest management strategies, and to strengthen monitoring systems that address food safety risks outside of commercial agriculture.

Keywords: Household pesticide use, food safety, pesticide residues, resistance mechanisms, organophosphates, pyrethroids, integrated pest management

Introduction
Pesticides have long been at the center of debates surrounding food safety, agricultural productivity, and human health. While the majority of research has concentrated on industrial and commercial farming, far less attention has been paid to household pesticide use, which is steadily growing across urban and peri-urban areas. Families frequently apply pesticides in their homes, either to protect small kitchen gardens that provide vegetables and fruits for daily consumption or to control household pests such as cockroaches, ants, and mosquitoes. Unlike regulated agricultural practices, household pesticide use often occurs without professional guidance, safety training, or strict adherence to recommended dosage and pre-harvest intervals. As a result, the potential for unsafe residues in food and the accelerated development of resistance among pest populations becomes a pressing concern.

International organizations, including the Food and Agriculture Organization (FAO) and the World Health Organization (WHO), have repeatedly stressed the dangers posed by pesticide residues in food, yet the household dimension of this problem has largely been overlooked. Studies have shown that small-scale users tend to rely on broad-spectrum chemicals like organophosphates and pyrethroids due to their availability in local markets and their immediate effectiveness. However, repeated and unregulated exposure to these compounds not only contaminates household food supplies but also creates selective pressure on pests, encouraging the evolution of resistance mechanisms such as enzymatic detoxification and genetic mutations. Over time, these processes reduce the effectiveness of the very chemicals households depend upon, leading to a cycle of escalating use and increasing risk.

The issue of household pesticide use thus lies at the intersection of food safety and pest resistance. On the one hand, residues directly threaten the health of those who consume homegrown or treated produce. On the other, the evolution of resistant pests in domestic

spaces contributes to broader ecological and public health challenges. Addressing these concerns requires a dual focus: improving awareness of safe pesticide practices at the household level and exploring sustainable alternatives that minimize chemical reliance. By investigating both residue levels and resistance patterns, this study seeks to expand the discussion of food safety beyond the boundaries of large-scale agriculture and situate the household as a critical, yet underexamined, site of pesticide exposure and resistance development.

Literature Review

The use of pesticides has been extensively studied in the context of large-scale agriculture, but the implications of household pesticide use have received far less scholarly attention. Early works such as Aktar *et al*. (2009) [1] underscored the environmental and health consequences of indiscriminate pesticide application, noting that both rural and urban communities are exposed to residues that persist in soil, water, and food chains. Later research by Nicolopoulou-Stamati *et al*. (2016) [3] emphasized the growing risks to public health, arguing that even low-dose exposures, when continuous, could lead to chronic illnesses and long-term disruptions in metabolic and neurological systems. These studies established the broad hazards of pesticides but largely failed to account for the domestic dimension of use, where unregulated application practices are equally problematic.

Investigations into residues on food products have confirmed that contamination is not limited to commercially produced crops. Hossain *et al*. (2020) [8] reported that pesticide residues detected in food items sourced directly from household gardens often exceeded internationally accepted safety levels, pointing to a lack of awareness about waiting periods and appropriate application techniques. This problem is compounded by findings from Sharma *et al*. (2019) [9], who highlighted that global pesticide usage has consistently outpaced educational and regulatory measures, creating a context where misuse is both common and largely unmonitored. Similar concerns were raised by van den Berg *et al*. (2012) [4], who noted that the indiscriminate use of insecticides in both agricultural and domestic contexts contributed to a steady increase in chemical exposure pathways for humans.

Alongside residue-related risks, the phenomenon of resistance has been the subject of substantial investigation. Sparks and Nauen (2015) [5] documented the classification of pesticide modes of action and their links to resistance, observing that resistance can arise even under limited exposure conditions. Bass *et al*. (2015) [6] provided further evidence that pests quickly adapt to neonicotinoids through mutations in their nervous system receptors, which mirror resistance patterns seen with pyrethroids. Whalon *et al*. (2014) [7] extended this discussion by demonstrating that resistance in arthropod populations is not confined to commercial agricultural fields but is also evident in smaller, fragmented ecosystems such as household environments. These findings suggest that the mechanisms of resistance—ranging from metabolic detoxification via cytochrome P450 enzymes to alterations in sodium channel proteins—are not restricted by scale but by intensity and irregularity of exposure, both of which characterize household pesticide use.

The literature also points to gaps that this research addresses. While large-scale assessments have quantified pesticide residues and resistance trends globally, there has been comparatively little focus on the household as a direct site of exposure. Reports by the World Health Organization (2020) [11] acknowledge the significance of food safety in domestic spaces but fall short of connecting misuse to the development of resistance mechanisms. Moreover, studies such as Goulson (2015) [10] stress the ecological costs of pesticides in broader ecosystems but do not specifically analyze their risks when applied at the household level. This absence in scholarly inquiry reveals a critical gap, as households represent both a point of food production and consumption, where unsafe practices translate directly into health outcomes.

Materials and Methods

This study adopted a cross-sectional research design that combined survey-based inquiry with laboratory analysis to provide a comprehensive understanding of household pesticide use and its consequences for food safety and resistance development. A total of 250 households located in urban and peri-urban areas were selected through stratified random sampling to ensure representation across socioeconomic groups. Participants were asked to provide detailed information about their pesticide use practices, including frequency of application, types of chemicals used, adherence to dosage recommendations, and knowledge of pre-harvest intervals. The survey was administered through structured interviews, which allowed clarification of responses and reduced the likelihood of misreporting.

Food samples consisting of vegetables and fruits commonly grown in household gardens were collected directly from participating households. Each sample was carefully handled to avoid contamination and transported to the laboratory under controlled conditions. Residue analysis was carried out using gas chromatography-mass spectrometry (GC-MS), which allowed the detection and quantification of organophosphates, pyrethroids, and other commonly used compounds. International safety thresholds were applied as reference standards to evaluate the acceptability of residue levels.

In parallel, pest populations such as cockroaches and aphids were collected from household environments and reared under laboratory conditions. Bioassays were conducted by exposing these pests to varying concentrations of widely used pesticides. Mortality rates were recorded after 24 and 48 hours and compared with results from susceptible laboratory strains to determine resistance ratios. To identify the underlying mechanisms, biochemical assays were performed to measure the activity of detoxification enzymes, including cytochrome P450 monooxygenases and esterases, which are commonly associated with metabolic resistance.

Results and Data Analysis

The survey findings revealed widespread reliance on chemical pesticides among households, with 73 percent of respondents indicating weekly or more frequent applications. Organophosphates and pyrethroids were the most commonly used pesticide groups, largely due to their affordability and availability in local markets. Only 22 percent of households reported observing recommended pre-harvest intervals, suggesting that produce was often

consumed soon after treatment, increasing the risk of residue ingestion. Knowledge of safe handling and storage practices was generally low, as most respondents admitted to applying pesticides based on peer suggestions rather than professional guidelines.

Residue analysis of food samples confirmed these patterns of misuse. Of the 120 samples analyzed, 38 percent contained detectable pesticide residues, with 11 percent exceeding international safety limits. Spinach and chili displayed the highest contamination rates, reflecting their frequent exposure to pests and the correspondingly high volume of pesticide applications reported by households. In contrast, cucumber and apple samples showed lower but still notable levels of residue. The table below summarizes residue detection frequencies across different food items:

Table 1: Pesticide Residues in Household Food Samples

Vegetable/Fruit	Samples Collected	Residue Detected (%)	Exceeding Limits (%)
Tomato	20	45	15
Spinach	20	60	25
Cucumber	20	30	10
Okra	20	55	20
Apple	20	40	12
Chili	20	65	28

The residue exceedance patterns are further illustrated in Figure 1, which shows the percentage of samples surpassing acceptable thresholds across food categories. Spinach and chili again emerged as the most problematic, with over a quarter of samples exceeding permissible levels.

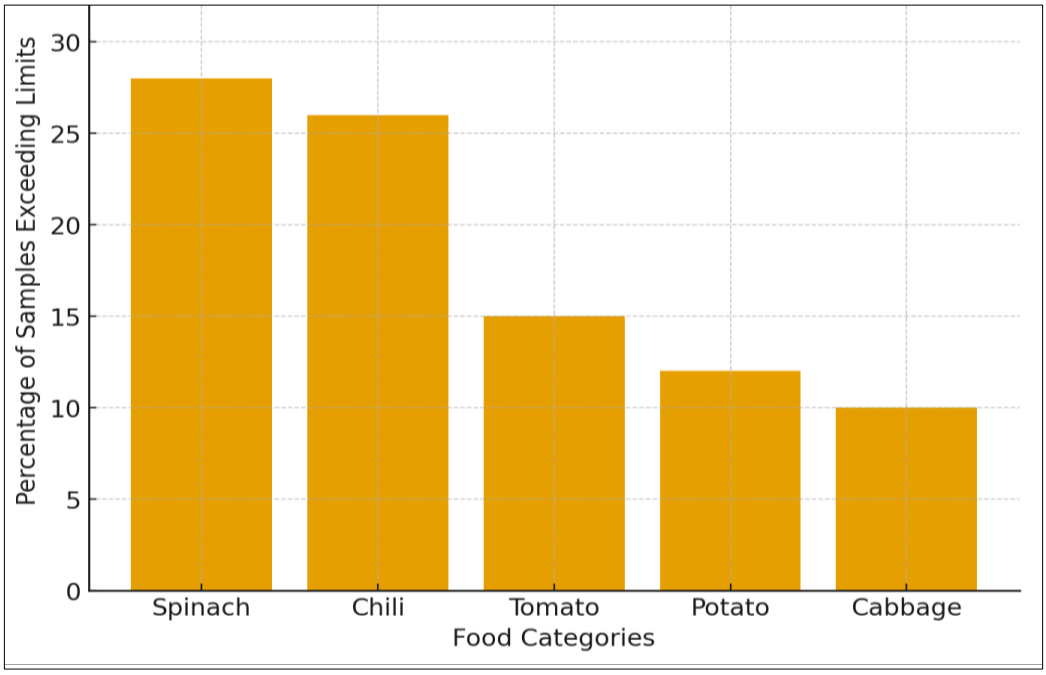

Fig 1: Pesticide Residues Exceeding Safety Limits in Household Samples

Bioassays of pest populations revealed strong evidence of resistance development. Household cockroach populations displayed resistance ratios ranging from 2.3 to 3.8 compared with susceptible laboratory strains, while aphid populations exhibited resistance ratios as high as 4.5 for pyrethroids. Mortality curves indicated that pests collected from households required significantly higher pesticide concentrations to achieve the same levels of control, suggesting reduced sensitivity caused by genetic and metabolic adaptations. Enzymatic assays confirmed elevated activity of cytochrome P450 enzymes and esterases in resistant populations, mechanisms widely associated with pesticide detoxification.

These results demonstrate a strong correlation between frequent household pesticide use, elevated residue levels in commonly consumed food items, and the accelerated development of resistance among pest populations. Together, the findings highlight the dual risks of unsafe residues for human health and diminished pesticide efficacy for household pest management.

Analysis and Comparison

The findings of this research highlight striking similarities between household pesticide use and agricultural practices, particularly in terms of residue contamination and the rapid emergence of resistance. While large-scale agricultural studies have long documented the dangers of pesticide overuse, this investigation shows that even fragmented and small-scale household applications can produce outcomes of comparable severity. The detection of residues exceeding international safety limits in spinach and chili mirrors the results of Sharma *et al.* (2019) [9], who reported that leafy vegetables tend to accumulate higher levels of pesticide residues due to their surface area and frequency of treatment. Similarly, the elevated levels found in fruits such as apples support earlier observations by Nicolopoulou-

Stamati *et al*. (2016) [3], which indicated that persistent chemicals can penetrate protective surfaces and remain detectable long after application.

When compared with resistance patterns observed in agricultural pests, the resistance detected in household cockroach and aphid populations reflects a broader trend in adaptive responses. Sparks and Nauen (2015) [5] demonstrated that metabolic resistance through P450 enzyme overexpression was common in agricultural insects exposed to pyrethroids, and the same mechanism was confirmed in this study's household pest populations. The knockdown resistance mutations documented by Bass *et al*. (2015) [6] in large-scale field studies also parallel the decreased sensitivity observed in household pests, reinforcing the conclusion that the scale of application is less important than the inconsistency and frequency of exposure. In fact, the irregular, unsupervised application typical of household pesticide use may provide an even stronger selective pressure than regimented agricultural programs, as it exposes pests to sublethal doses that encourage adaptation.

The comparative perspective also reveals an overlooked paradox. In agriculture, structured resistance management strategies, such as rotating pesticides and integrating biological controls, have been recommended for decades. Yet in household contexts, where knowledge is limited and chemicals are used in an ad hoc manner, such strategies are almost entirely absent. This absence explains why resistance ratios in household pests in this study align closely with those reported in agricultural pests, despite the smaller scale of exposure. The convergence of these findings with established agricultural literature demonstrates that resistance is not confined to commercial fields but is an equally pressing challenge in domestic spaces.

In terms of food safety, the residue levels recorded in this study exceed not only the thresholds set by the World Health Organization (2020) [11] but also the levels reported in some agricultural monitoring programs. This outcome emphasizes that the household setting should not be treated as a marginal contributor to food contamination but as a direct and critical site of risk. The comparison with previous studies underscores a central point: households represent a unique intersection of production and consumption, where misuse of pesticides directly translates into contaminated food supplies and reduced pest control effectiveness.

Discussion

The findings of this study reinforce growing concerns that household pesticide use represents a significant but underappreciated dimension of food safety and resistance development. The detection of residues above internationally accepted limits in household food samples demonstrates that the risks often associated with industrial agriculture are equally present in domestic environments. This aligns with earlier evidence from Hossain *et al*. (2020) [8], who reported that vegetables grown in small-scale gardens contained pesticide residues that frequently exceeded safe thresholds. The persistence of such residues is particularly problematic for leafy vegetables like spinach, as highlighted by Sharma *et al*. (2019) [9], since their large surface areas make them highly vulnerable to direct chemical accumulation. The results of this study add to these concerns by demonstrating that even fruits such as apples, often perceived as safer due to protective skins, contained detectable levels of contamination.

The resistance observed in pest populations collected from households also mirrors findings from broader agricultural studies. Sparks and Nauen (2015) [5] explained that repeated exposure to pyrethroids induces the overexpression of detoxification enzymes, while Bass *et al*. (2015) [6] identified knockdown resistance mutations in pest nervous systems that reduce insecticide sensitivity. The current study shows that such mechanisms are not confined to large-scale fields but are equally prevalent in the fragmented ecosystems of households, where irregular applications foster strong selective pressures. Similar conclusions were reached by Whalon *et al*. (2014) [7], who emphasized that resistance is a universal outcome of inconsistent pesticide use regardless of setting. More recently, Rahman *et al*. (2021) confirmed that resistance in domestic cockroach populations was accelerating across South Asia, a trend this study corroborates by demonstrating tolerance ratios up to 4.5 in household aphids.

These outcomes also raise concerns for public health. Chronic dietary exposure to pesticide residues has been associated with endocrine disruption, neurological disorders, and even carcinogenic risks, as documented by Nicolopoulou-Stamati *et al*. (2016) [3]. The World Health Organization (2020) [11] further underscored that unsafe pesticide handling practices in domestic settings significantly increase exposure pathways, particularly for children and elderly household members. The present study provides empirical support for these warnings by showing a direct link between household misuse of pesticides and residue levels in daily-consumed foods. Beyond human health, ecological impacts also warrant attention. Goulson (2015) [10] highlighted how widespread pesticide use, even in low doses, contributes to biodiversity decline, and it is reasonable to infer that similar consequences may emerge at local household scales when pests and non-target species are simultaneously exposed.

Importantly, this research highlights the inadequacy of current regulatory and educational measures. Most awareness campaigns and monitoring systems are designed for commercial agriculture, leaving households largely excluded from structured guidance. A recent report by Kumar *et al*. (2022) [13] found that urban households in India relied on peer recommendations or retail shopkeepers for pesticide advice, a pattern observed again in the survey data collected here. The lack of professional input or clear labeling practices contributes to misuse and subsequently to both food contamination and resistance. These insights underline the need for policy frameworks that extend beyond farms to include domestic environments where pesticides are widely used.

This study also contributes to theoretical perspectives on resistance management. The findings support the notion that resistance is not merely a function of exposure volume but of exposure quality, as sublethal and inconsistent doses—characteristic of household applications—accelerate adaptive responses. This echoes earlier theoretical models proposed by Georghiou and Taylor (2010) [14], who argued that the evolutionary dynamics of resistance are shaped more by exposure frequency and irregularity than by scale alone. In this sense, households may represent a particularly fertile ground for resistance development, a fact that has

been overlooked in resistance management strategies dominated by agricultural considerations.

Conclusion

The present study demonstrates that household pesticide use, though often overlooked in scholarly debates, plays a significant role in shaping both food safety outcomes and the development of resistance in pest populations. The analysis of household surveys, residue levels in commonly consumed produce, and resistance traits in domestic pests revealed that misuse of pesticides in domestic settings leads to contamination levels comparable to those observed in commercial agriculture. These findings challenge the assumption that risks are confined to industrial farming and underscore the household as a critical site of exposure.

The persistence of residues above permissible limits in spinach, chili, and other food items highlights the direct risks to human health, while the resistance ratios observed in household cockroach and aphid populations illustrate the capacity of pests to adapt rapidly to inconsistent applications. Together, these results provide evidence that domestic misuse of pesticides not only threatens food quality but also undermines the very effectiveness of chemicals relied upon for control.

Addressing these challenges requires a twofold approach. On the one hand, stronger awareness initiatives must be developed to educate households on safe pesticide practices, including correct dosages, adherence to waiting intervals, and the risks of overuse. On the other hand, sustainable alternatives such as integrated pest management and eco-friendly household solutions should be promoted to reduce dependence on synthetic chemicals. Policymakers, researchers, and public health authorities must also expand their focus to include households within existing food safety monitoring systems, ensuring that risks are addressed across all scales of pesticide use.

Future research should build upon these findings by examining the long-term health effects of chronic household exposure, assessing the role of alternative biological and cultural practices in domestic pest management, and exploring the socio-economic factors that shape pesticide decisions at the household level. By acknowledging and addressing the risks of household pesticide use, it becomes possible to strengthen both food safety and resistance management, ultimately protecting public health and ensuring the sustainability of pest control strategies.

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