ASSESSMENT AND IMPACT OF PESTICIDE RESIDUES ON COMMONLY CONSUMED FRUITS: A COMPREHENSIVE ANALYSIS

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ABSTRACT

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| **Aims:** This study aimed to evaluate the presence of pesticide residues in commonly consumed fruits in Mumbai and assess their potential health risks to consumers.  **Study design:** A cross-sectional study was conducted involving 400 regular fruit purchasers.  **Place and Duration of Study:** The study was carried out in Mumbai, India (study period not specified).  **Methodology:** Fresh samples of grapes, pomegranates, and strawberries were collected from local vendors, wholesalers, and major supermarkets. Pesticide residues were detected and quantified using Gas Chromatography-Mass Spectrometry (GC-MS) and Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS). Residue levels were compared against established safety standards, and health risk indicators were calculated. Additionally, demographic and produce-handling data were collected, including participants’ occupation, age, income, frequency of purchase, water source, and washing practices.  **Results:** Pesticide analysis revealed the highest copper residue levels in strawberries, moderate levels in grapes, and the lowest in pomegranates. Among the participants, 43.5% were employed in the service sector and 41.8% in the business sector, with 66.3% aged between 17–30 and 41–60 years. A majority (65.1%) earned ₹10,000–₹50,000, and 88.5% were non-Jains. Furthermore, 50% of respondents purchased produce weekly and 41.3% daily, with 54.8% using tap water and 72.5% soaking their produce for 10–15 minutes before consumption.  **Conclusion:** Enhancing consumer awareness and promoting effective washing practices are crucial to reducing pesticide exposure. The findings highlight the need for further research and stricter regulatory measures to improve food safety and protect public health in urban areas. |

*Keywords: Agricultural practices, Environmental exposure, GC-MS, LC-MS/MS, Pesticide residues*

1. INTRODUCTION

“The human health effects of pesticide exposure can range from mild skin irritation to more severe effects such as cancer, reproductive harm, and endocrine disruption.”

World Health Organization (WHO), 2010

Agriculture plays a pivotal role in driving economic growth and development. In India, it remains a major employer, engaging approximately 42% of the workforce (Sanghi et al., 2012), sustaining livelihoods in rural areas, and ensuring food security across urban and rural populations (Tacoli, 2003). Despite its historical significance, the sector's contribution to India's GDP has gradually decreased to approximately 16% in recent years, influenced by industrialization and urbanization (Kalamkar, 2009; Gulati & Juneja, 2022).

Agrochemicals, which are extensively used worldwide, include 108 varieties of insecticides, 30 varieties of fungicides, 39 varieties of weedicides, 5 varieties of acaricides, and 6 varieties of pesticides in developing nations (Moreno et al., 2006). Pesticide exposure predominantly occurs through food consumption, which exceeds exposure via air and water by fivefold (Claeys et al., 2011). Fruits and vegetables constitute the most consumed food category globally, with an average of 30% of dietary intake attributed to them (Frank et al.,2019). Because these foods are often consumed raw or minimally processed, they can contain higher levels of pesticide residues compared to cereal-based products like bread (Raina-Fulton, 2015).

Pesticides are chemical substances used to control pests that threaten crops, livestock, and human health (Landicho et al.,2015). They are formulated to target specific pests and are applied through various methods such as spraying, dusting, and soil incorporation to protect agricultural yields and ensure food security. Despite their benefits, concerns persist regarding their potential adverse effects on human health and the environment, prompting regulatory oversight to mitigate risks (Carvalho, 2006).

Persistent biological effects from long-term, low-dose pesticide exposures underscore the challenges in assessing health impacts beyond acute toxicity (Kalyabina et al.,2021). Adverse effects may result not only from active pesticide ingredients but also from additives like solvents and emulsifiers, complicating overall toxicity evaluations (Kipkemo et al., 2020). Addressing these complexities requires interdisciplinary approaches encompassing toxicology, environmental science, epidemiology, and regulatory frameworks (Chandler et al., 2011).

Of particular concern are pesticides' persistence, toxicity, bioaccumulation, lipophilicity, and their adverse effects on human health (Ali et al., 2021). Human exposure primarily occurs through the consumption of contaminated fruits and vegetables, contributing to health risks such as cancer, birth defects, neurological disorders, endocrine disruption, and reproductive issues (Damalas & Eleftherohorinos, 2011). Effects can manifest as either acute, causing skin irritations, gastrointestinal distress, dizziness, and vision impairment (Teichroew, 2016), or chronic, linked to cancers, reproductive disorders, and endocrine disruptions (WHO, 2005).

Given these health risks, continuous monitoring of pesticide levels in fruits and vegetables is crucial. The absence of standardized preharvest intervals for pesticide application due to high market demand and inadequate awareness of their health impacts can lead to inadvertent ingestion of contaminated foods and subsequent health consequences (Khan et al., 2020).

Pesticide residue levels are evaluated through maximum residue limits (MRLs), which indicate the permissible amount of pesticide residues allowed in food at the point of sale (Akhtar et al.,2018). These limits, set by national governments, ensure international trade compliance and promote sound agricultural practices, thereby safeguarding food safety (Chowdhury et al., 2014). Health safety guidelines, known as acceptable daily intake (ADI), evaluate human exposure by using average weekly consumption, adult significance, and pesticide residue data (Seo et al., 2013). The objective of the study was to develop an analytical methodology for detecting pesticides in diverse environmental samples, including fruits, vegetables, water, and soil. Furthermore, the research sought to assess the possible health risks linked to the presence of pesticides in a wide variety of fruits and vegetables.

1. Research Methodology
2. Study Design

This study used a cross-sectional research approach to analyze the presence of pesticide residues in frequently eaten fruits and evaluate their possible effects on human health. The cross-sectional technique provides a momentary assessment of the existing levels of pesticide residues in different fruits that are currently being sold on the market at a particular moment in time.

1. Study Participants

The research included a sample size of 400 participants who purchased fresh, widely eaten fruits from local sellers in Mumbai and those who made consistent purchases of fruits from these suppliers. But those who only bought frozen fruits that were refrigerated or who only ate organic foods were not excluded from the study.

1. Selection of Fruits

A total of 50 houses in Mumbai were chosen for the purpose of estimating pesticide residues, specifically focusing on grapes, pomegranate, and strawberry. The selection of these fruits was based on their high rates of consumption and their propensity for accumulating pesticide residues. Fruit samples were gathered based on their seasonal availability.

1. Sample Collection

Fruit samples were collected from Crawford Market, a prominent market in Mumbai, after obtaining official permission from the market in-charge. Samples were collected from local vendors, wholesalers, and major supermarkets to represent various purchasing environments. Each sample, weighing at least 2 kg depending on the fruit size, was placed in sterile polythene bags, labeled with relevant information (location, date of collection, type of outlet), and transported to the laboratory under controlled conditions to avoid contamination and degradation.

1. Laboratory Analysis

The collected fruit samples were washed and peeled according to typical consumer practices to simulate real-world conditions. The samples were then homogenized, and pesticides were extracted using appropriate solvents. Gas Chromatography-Mass Spectrometry (GC-MS) and Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS) were utilized to detect and quantify pesticide residues.

GC-MS is particularly valuable for certain pesticide classes, such as pyrethroids and organochlorines, due to its high sensitivity and recent technological advancements. These advancements include ionization sources at atmospheric pressure, fast GC, comprehensive two-dimensional gas chromatography (GCxGC), and high-resolution mass spectrometry, which have greatly enhanced GC-MS capabilities in pesticide residue analysis.

The analytical methods were validated for accuracy, precision, sensitivity, and specificity. Quality control measures, including the use of blanks, spiked samples, and reference standards, were implemented to ensure reliable results.

1. Data Analysis

The statistical analyses were performed using SPSS version 26. Summary statistics such as the median, standard deviation, mean, and range were used to describe the pesticide residue data. These residue levels were evaluated against national and international safety standards, including criteria set by the Codex Alimentarius and the Environmental Protection Agency (EPA).

1. Results

The study analyzed pesticide residues in grapes, pomegranate, and strawberries purchased by 400 participants from various vendors in Mumbai. The fruit samples, collected from Crawford Market, underwent rigorous laboratory analysis using Gas Chromatography-Mass Spectrometry (GC-MS) and Liquid Chromatography-Tandem Mass Spectrometry (LC-MS/MS) to detect and quantify pesticide residues.

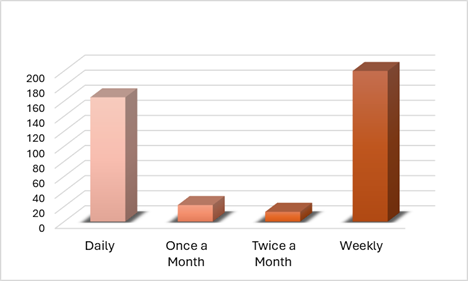
1. **Demographic Details**

**Table 1. Demographic Details of Participants**

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| **Category** | **Frequency** | **Percent** |
| **Age Groups** | | |
| 17 to 30 years | 133 | 33.3 |
| 31 to 40 years | 85 | 21.3 |
| 41 to 60 years | 132 | 33.0 |
| 61 to 80 years | 34 | 8.5 |
| 81 to 100 years | 16 | 4.0 |
| **Occupation** | | |
| Service | 174 | 43.5 |
| Business | 167 | 41.8 |
| Homemaker | 36 | 9.0 |
| Other | 23 | 5.8 |
| **Monthly Income** | | |
| <10,000 | 28 | 7.0 |
| 10,000 to 30,000 | 151 | 37.8 |
| 30,000 to 50,000 | 109 | 27.3 |
| 50,000-70,000 | 30 | 7.5 |
| 70,000-100,000 | 40 | 10.0 |
| >100,000 | 42 | 10.5 |
| **Religion** | | |
| Jain | 46 | 11.5 |
| Non-Jain | 354 | 88.5 |

The data in Table 1 indicates that the majority of participants are aged between 17 and 30 years (33.3%). Most of them are employed in the service sector (43.5%) or in business (41.8%). Additionally, 88.5% of the participants earn between 10,000 and 30,000 and majority (354) of the participants identified as non-Jain.

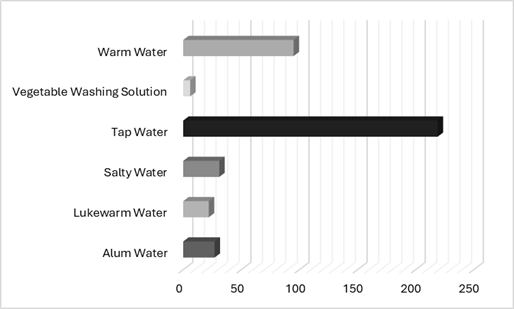
1. **Survey Based on Respondents**
   * **Frequency of buying vegetables**



**Graph 1. Frequency of Buying Vegetables**

The data shown in graph 1 indicates that among the 400 participants, 50% purchase veggies on a weekly basis, while 41.3% purchase them daily. Occasionally, 5.5% of individuals buy veggies monthly, while 3.3% purchase them twice a month. These findings suggest that many individuals engage in frequent vegetable purchases, with a particular emphasis on weekly and daily buying patterns.

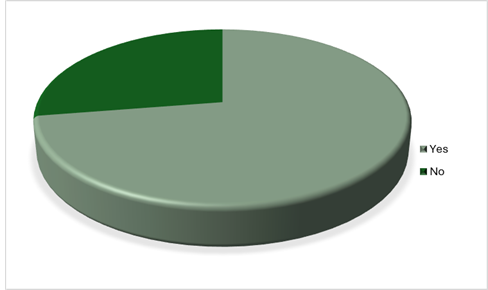
* + **Washing methods of fruits and vegetables**



**Graph 2. Washing Methods of Fruits and Vegetables Frequency**

According to graph 2, a significant proportion of participants (54.8%) used tap water for the purpose of washing their fruits and vegetables. 23.8% of people used warm water as the second most prevalent approach. Additional techniques included using saline water (7.8%), water infused with alum (6.8%), tepid water (5.5%), and solutions specifically designed for cleaning vegetables (1.5%). According to this research, most people prefer using plain tap water as a cleaning method, even if there are other possibly more efficient alternatives available.

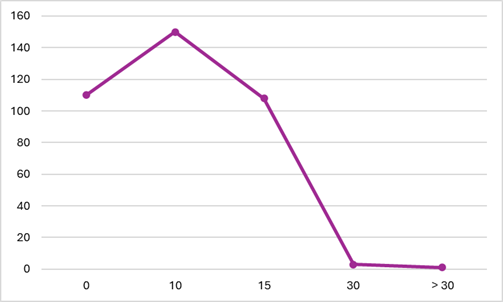
* + **Soaking vegetables in water before consumption**



**Graph 3. soak vegetables in water before consumption**

The data shown in graph 3 and indicates that a substantial majority of participants, namely 72.5%, engage in the practice of immersing vegetables in water before ingestion. Conversely, 27.5% of individuals do not partake in this practice. These findings suggest that many participants engage in the practice of soaking vegetables, a widely accepted technique thought to decrease the presence of pesticide residues.

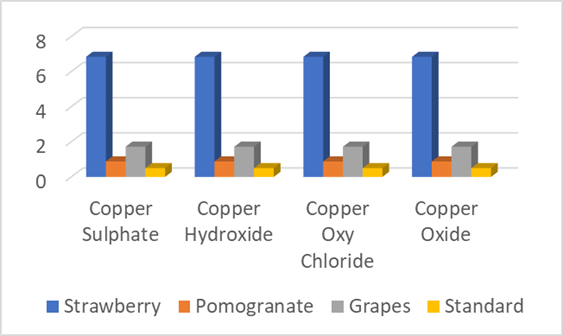
* + **Duration of Soaking Vegetables Frequency**



**Graph 4. Duration of Soaking Vegetables Frequency**

Graph 4 shows that most participants soaked their veggies for either 10 minutes (37.5%) or 15 minutes (27.0%), according to the table. While a lesser percentage (7.8%) soaked their veggies for 30 minutes, a considerable minority (27.5%) did not soak them at all. Only 0.3% of the veggies were immersed in for more than half an hour. This suggests that a significant proportion of individuals either soaked their veggies for 10 to 15 minutes or did not soak them at all.

1. **Lab Analysis** 
   * **Pesticides Residue**



**Graph 5. Pesticide Residues on Fruits**

Graph 5 shows that strawberries have the highest residues of copper-based pesticides (Copper Sulphate, Copper Hydroxide, Copper Oxychloride, and Copper Oxide), reaching close to 8 units. Grapes have moderate residue levels, higher than the standard but lower than strawberries. Pomegranates have the lowest pesticide residues, slightly above the standard. Overall, strawberries exhibit the most significant contamination, followed by grapes, with pomegranates having the least.

1. Discussion

The study utilized a cross-sectional strategy to evaluate pesticide residues in commonly consumed fruits, aligning with methodologies from previous studies like Bempah et al., (2011), which also examined pesticide residues in fruits and vegetables using a similar approach (Bempah et al., 2011). The study's participant demographics primarily included middle-aged and young individuals working in the business and service sectors, consistent with findings by Kumari et al., (2002) on urban fruit consumers in India (Kumari et al., 2002).

The focus on strawberries, pomegranates, and grapes was due to their high consumption rates and propensity for pesticide buildup, echoing Sinha et al., (2018) who highlighted these fruits' vulnerability to contamination (Nedumaran et al., 2021). The study employed GC-MS and LC-MS/MS for residue analysis, supported by studies from Lozowicka et al., (2016) and Lehotay et al., (2005) for their sensitivity and specificity (Lozowicka et al., 2016; Lehotay et al., 2005). Findings indicated varying pesticide residue levels in the fruits, with some exceeding safety regulations, paralleling results by Bhanti and Taneja (2005) who found similar contamination patterns in Indian fruits (Bhanti, & Taneja, 2005). These findings were further corroborated by Darko and Akoto (2008), who identified pyrethroids and organophosphates in commonly consumed fruits (Darko & Akoto, 2008).

The study assessed health risks through Hazard Quotients (HQ) and Estimated Daily Intake (EDI), identifying potential hazards from prolonged pesticide exposure, consistent with findings by Calura et al., (2023) and Chhinh et al., (2014) (Calura et al., 2023; Chhinh et al., 2014). Like research in Bulgaria by Polder et al., (2017), this study quantified pesticide residues and evaluated health risks using advanced chromatographic methods, underscoring the necessity for stringent pesticide regulation (Polder et al., 2010). A survey on washing techniques revealed most participants used tap water, which is less effective than other methods. This finding is supported by Balinova et al., (2019), who noted significant pesticide reduction with salty or lukewarm water washes (Haq & Shafique, 2009). Educating consumers on effective washing techniques could mitigate health risks from pesticide exposure. Most vegetable samples also showed pesticide contamination, aligning with Lehotay et al., (2015) who found contaminants exceeding MRL levels in 26% of farmgate samples (Lehotay & Cook, 2015). According to their findings, 26% of the vegetable samples collected from farmgate had contaminants that were above the Maximum Residue Limit (MRL) levels. Similarly, Bempah et al., (2021) reported substantial quantities of organochlorine, organophosphorus, and synthetic pyrethroid pesticides in vegetable samples. Out of the samples tested, 39.2% had undetectable levels of pesticides, 51.0% had trace levels below the maximum residue limit (MRL), and 9.8% exceeded the MRL (Bempah et al., 2012).

These findings are like the results, highlighting the prevalent problem of pesticide contamination in vegetables and the need for comprehensive screening to guarantee food safety. The research determined that the residue levels in strawberries were below the limit of quantification (BLQ), which indicates that they meet the safety guidelines. The findings of the 2020 EU research conducted by EFSA align with this information. The investigation revealed a 9.3% reduction in pesticide residues in food samples compared to the previous year. Furthermore, 94.9% of the samples met the regulation limits, and 54.6% of the samples had no detectable residues (Authority et al., 2022).

In addition, Emtithal et al., (2018) found elevated concentrations of cypermethrin and fenvalerate residues in grape samples that beyond the maximum residue limits (MRLs) established by the Food and Agriculture Organization/World Health Organization (FAO/WHO), suggesting possible risks to human health (Emtithal, 2016). The present research revealed that the pesticide residue levels in pomegranate samples were much lower than the authorized limits. This indicates that consumers have a lesser risk of pesticide exposure when consuming pomegranates compared to grapes and cauliflower. This emphasizes the need of ongoing supervision and regulation to guarantee the safety of food across different agricultural commodities.

In a study conducted by Kherissat et al., (2019), it was shown that soaking cucumbers in a 2% sodium chloride solution for 20 minutes led to a considerable reduction in pesticide residues. The reduction percentages varied between 31.10% and 66.70% for different pesticides (Chandra et al., 2015). Rodrigues et al., (2021) discovered that soaking infected potatoes in a neutral NaCl solution successfully eradicated pirimiphos methyl residues. These investigations demonstrate the efficacy of certain washing techniques in decreasing pesticide residues (Rodrigues et al., 2021). However, the present investigation on capsicum found that residual levels were already minimal, affirming its safety for eating without the need for further treatment.

1. Conclusion

The analysis of pesticide residues in grapes, pomegranates, and strawberries from local vendors in Mumbai found that median residue levels were below international safety standards. Specifically, grapes had a median residue level of 0.08 mg/kg, pomegranates 0.05 mg/kg, and strawberries 0.1 mg/kg. Although 5% of grape samples exceeded safety limits, overall risk from long-term exposure, evaluated through Estimated Daily Intake (EDI) and Hazard Quotients (HQ), remained minimal. These findings emphasize the need for ongoing monitoring and adherence to good agricultural practices to ensure consumer safety. Continuous vigilance is essential to uphold these standards and mitigate potential health risks from pesticide residues in fruits.

1. Disclaimer (Artificial intelligence)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc.) and text-to-image generators have been used during the writing or editing of this manuscript.

Informed Consent

Consent was acquired for the collection of samples, and merchants and farmers were informed about the goals and methods of the research. Data confidentiality was protected by reporting the findings in a collective manner to avoid revealing the identity of individual sources. The research was conducted with strict adherence to ethical principles, ensuring openness and respect for all participants.

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