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Metal Phosphide Poisoning in Suicide Cases: A Four-Year Retrospective Forensic and Socio-demographic Study from Asyut Governorate, Upper Egypt (2021–2024)

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Abstract: **Background:** Metal phosphide compounds, most notably aluminum and zinc phosphide, are extremely toxic pesticides that are associated with a high case-fatality rate following intentional ingestion. In Upper Egypt, these compounds are frequently implicated in suicide, yet region-specific forensic data remain limited. **Objective:** To retrospectively characterize the forensic, toxicological, and sociodemographic profiles of confirmed suicide deaths due to metal phosphide poisoning in Asyut Governorate, Upper Egypt, from 2021 to 2024. **Methods:** A retrospective observational study was conducted on suicide-related metal phosphide poisoning deaths examined at the Forensic Medicine Authority, Asyut Branch. Data were obtained from medico-legal autopsy records, toxicology laboratories, and available hospital files. Included cases were confirmed suicides with toxicological evidence of metal phosphide and concordant medico-legal findings. Biological specimens were screened using the silver nitrate/phosphine test and confirmed by gas chromatography– mass spectrometry. Statistical analysis was performed using chi-square tests, with significance set at $p<0.05$. **Results:** All 245 cases were toxicologically confirmed and classified as suicide. Autopsy findings were characteristic of phosphine toxicity, with petechial hemorrhages (89.0%), pulmonary edema (84.0%), and hepatic and renal congestion (79.9%) being most frequent. A garlic-like odor in viscera was documented in 54.9% of cases. Case frequency declined in 2022 but increased thereafter, peaking in 2024, with a significant upward temporal trend (χ^2 for trend = 37.69, $p<0.001$). The third decade of life was most affected across both sexes, with marked sex-related seasonal variation and a consistent predominance of rural cases. **Conclusions:** Intentional metal phosphide poisoning remains a major cause of suicide- related mortality in Asyut Governorate, highlighting the urgent need for regulatory control and targeted suicide prevention strategies.

Key Words: Metal Phosphide, Suicide, Poisoning, Upper Egypt

INTRODUCTION

Metal phosphide compounds, particularly aluminum and zinc phosphide, are widely used agricultural fumigants in low- and middle-income countries because of their low cost and high efficacy. Upon ingestion or contact with moisture, metal phosphides generate phosphine gas, a potent cellular toxin that disrupts mitochondrial oxidative phosphorylation, leading to, severe metabolic acidosis, circulatory collapse, and multi-organ failure [1,2].

Owing to their extreme lethality, lack of a specific antidote, and rapid onset of toxicity, metal phosphides remain a common means of suicide, particularly in agricultural communities [3,4].

From a forensic perspective, the diagnosis of metal phosphide poisoning is challenging, as autopsy findings are often nonspecific and overlap with other causes of hypoxic death. Frequently reported findings include pulmonary edema, petechial hemorrhages, andvisceral congestion,

reflecting phosphine-induced oxidative stress and capillary damage [5,6]. Classical signs such as a garlic-like odor are inconsistently present, underscoring the necessity of toxicological confirmation. Despite the forensic and public health importance of metal phosphide poisoning, integrated studies combining autopsy findings, toxicological confirmation, and socio-demographic analysis remain limited.

The present study addresses this gap through a four-year retrospective forensic evaluation of confirmed metal phosphide poisoning deaths.

Study Methods

This retrospective observational study was conducted to characterize intentional (suicide-related) metal phosphide poisoning deaths in Asyut Governorate, Upper Egypt, from January 2021 to December 2024.

Data were obtained from the Forensic Medicine Authority (FMA), Asyut Branch, with supplementary information from affiliated toxicology laboratories, medico-legal autopsy units, and hospital records when available.

Eligible cases were defined as deaths classified as suicide based on medico-legal investigation, with toxicological confirmation of metal phosphide exposure and concordance between circumstantial evidence, autopsy findings, and toxicological results.

Accidental or homicidal poisonings, suspected cases without toxicological confirmation, incomplete records, and cases outside the study scope were excluded.

- Data were retrospectively extracted from medico-legal files, autopsy reports, toxicology records, and police investigation summaries using a standardized abstraction form
- Variables collected included demographic characteristics, residence, year and season of death, socioeconomic status, toxicological findings, and major autopsy findings
- Biological specimens analyzed included stomach contents, parts of the liver and gall bladder, halves of both kidneys, intestinal segments, and urinary bladder. Toxicological screening was performed using the silver nitrate/phosphine test, followed by confirmatory analysis with gas chromatography–mass spectrometry (GC–MS)
- Data analysis was performed using SPSS software. Categorical variables were summarized as frequencies and percentages and compared using chi-square tests, with statistical significance set at $p<0.05$
- Ethical approval and official permission were obtained from the relevant authorities. All data were anonymized, and reporting adhered to COPE and World Health Organization guidelines for research involving suicide

RESULTS

All included 245 cases were toxicologically confirmed and classified as suicide. Autopsy findings were consistent with phosphine toxicity,

Table 1 outlines the forensic and toxicological diagnostic framework applied in the present study. All included cases were classified as suicide based on medico-legal investigation. Toxicological analysis was performed on gastric contents and multiple visceral specimens, including liver, gall bladder, kidneys, intestinal segments, and urinary bladder. Specimens were collected separately and stored in tightly sealed containers. Initial screening was conducted using the silver nitrate/phosphine test, followed by confirmatory analysis with gas chromatography–mass spectrometry (GC–MS).

Petechial hemorrhages and pulmonary edema were the most frequent autopsy findings, while a smaller proportion of cases showed no significant gross abnormalities (Table 2).

In Table 3, The third decade constituted the largest age group (51.0%), followed by the second decade (30.2%), with a highly significant deviation from uniform distribution ($\chi^2 = 117.3$, $p<0.001$). Females slightly outnumbered males (52.7% vs 47.3%), although this difference was not statistically significant ($\chi^2 = 0.69$, $p = 0.406$). Rural residence was significantly more frequent than urban residence (66.9% vs 33.1%; $\chi^2 = 28.1$, $p<0.001$). Likewise, low socioeconomic status predominated (69.0%), showing a statistically significant difference compared with high socioeconomic status ($\chi^2 = 35.3$, $p<0.001$).

Values in bars indicate frequency and percentage of metal phosphide suicides relative to total suicides. Theproportion of metal phosphide suicides increased steadily over time, rising from 69.1% in 2021 to 89.8% in

Table 1: Toxicological Confirmation and Specimen Collection in Metal Phosphide Poisoning Cases

Parameter	Description
Manner of death	Suicide (100%)
Specimens collected	Stomach contents, part of liver and gall bladder, halves of both kidneys, parts of intestine, urinary bladder
Specimen handling	Separately collected, tightly sealed containers
Screening test	Silver nitrate / phosphine test
Confirmatory analysis	Gas chromatography–mass spectrometry (GC–MS)

Table 2: Common Autopsy Findings in Confirmed Metal Phosphide Poisoning Cases

Common autopsy finding	n (%)
Petechial hemorrhages	218 (89.0)
Pulmonary edema	204 (84.0)
Congested liver and kidneys	196 (79.9)
Garlic odor in viscera	132 (54.9)
No significant findings	15 (3.7)

Table 3: Sociodemographic Distribution of Suicide Cases due to Metal Phosphide Poisoning

Variable (χ^2)	Category	N	Percent (%)	Chi-Square	p-Value
Age	2nd decade	74	3.2	117.3	<0.001
	3rd decade	125	51		
	4th decade	27	11		
	Fifth decade	19	7.8 and more		
Sex	Male	116	47.3	0.69	0.406
	Female	129	52.7		
Residence	Rural	164	66.9	28.12	<0.001
	Urban	81	33.1		
Income	Low	169	69	35.3	<0.001
	High	76	31		

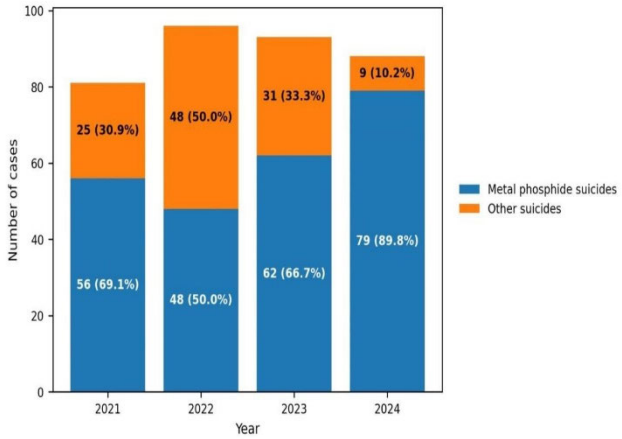

Figure 1: Annual Distribution of Total Suicide Cases and Metal Phosphide Suicide Cases in Asyut Governorate, 2021–2024

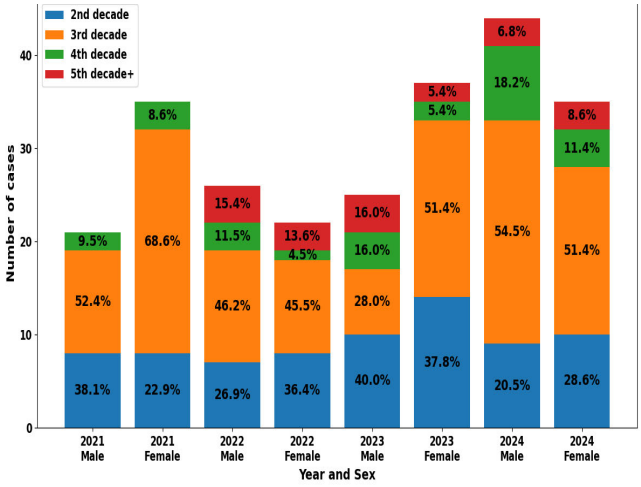

Figure 2: Age Distribution of Metal Phosphide Poisoning Deaths by Sex and Year (2021–2024)

2024, with a significant linear trend confirmed by chi-square analysis (χ^2 for trend = 37.69, p<0.001) (Figure 1).

Figure 2 illustrates the age-decade distribution of metal phosphide suicide cases by sex from 2021 to 2024. Across all study years and in both sexes, the third decade consistently represented the largest proportion of cases. In males, the third decade accounted for 52.4% in 2021, 46.2% in 2022, 28.0% in 2023, and 54.5% in 2024. A similar predominance was observed among females, with proportions of 68.6% in 2021, 45.5% in 2022, 51.4% in 2023, and 51.4% in 2024. The second decade constituted the next most frequent age group in both sexes, while the fourth decade contributed a smaller proportion of cases. Individuals in the fifth decade and above consistently represented the lowest proportion of cases throughout the study period, irrespective of sex.

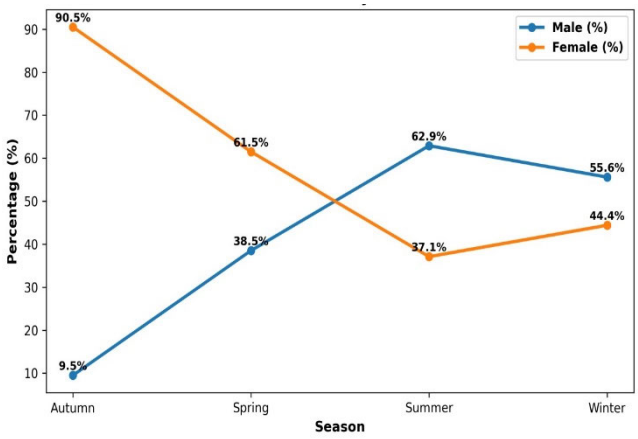

Figure 3: Seasonal Distribution by Sex, 2021–2024

Figure 3 shows the seasonal distribution of metal phosphide suicide cases by sex during the study period (2021–2024). Female cases predominated in autumn (90.5%) and spring (61.5%), whereas male cases were more frequent during summer (62.9%) and winter (55.6%). The seasonal distribution differed significantly by sex, with a chi-square test demonstrating a statistically significant association between season and sex ($\chi^2 = 69.54$, p<0.001).

Figure 4 presents the age-decade distribution of metal phosphide suicide cases by residence and year from 2021 to 2024. Across all study years and in both urban and rural settings, the third decade consistently represented the largest proportion of cases. In rural areas, the third decade accounted for 60.5% in 2021, 44.4% in 2022, 45.0% in 2023, and 61.5% in 2024. A similar predominance was observed in urban areas, with proportions of 50.0% in 2021, 31.6% in 2022, 36.8% in 2023, and 58.1% in 2024. The second decade constituted the next most frequent age group in both urban and rural residences, followed by the fourth decade.

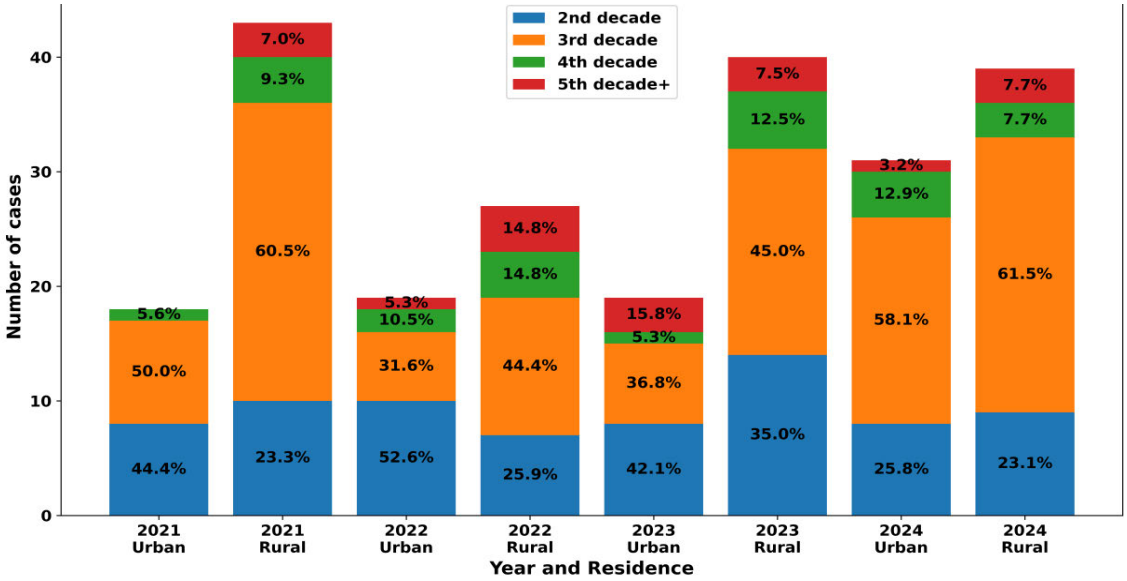

Figure 4: Age-Decade Distribution by Residence and Year

Individuals in the fifth decade and above consistently represented the smallest proportion of cases across all years and residence categories.

DISCUSSION

This study provides a medico-legal and toxicological characterization of fatal metal phosphide poisoning suicide cases in Asyut Governorate over a four-year period, demonstrating consistent demographic patterns, characteristic autopsy findings, and the central importance of definitive toxicological confirmation. The use of a two-step analytical strategy—screening by the silver nitrate/phosphine test followed by confirmatory GC– MS—enhanced diagnostic accuracy and reliability. Given the high volatility and rapid postmortem dissipation of phosphine gas, reliance on screening tests alone is insufficient and may result in misclassification of cause of death; confirmatory analysis therefore remains essential for accurate medico-legal determination. The combination of preliminary phosphine screening using silver nitrate–based assays with subsequent GC–MS confirmation constitutes a widely accepted forensic strategy for the diagnosis of metal phosphide poisoning. [1–6].

A notable finding of the present study is the increasing proportion of suicide deaths attributable to metal phosphide poisoning across the study years. This trend likely reflects the continued availability, low cost, and extreme lethality of aluminum and zinc phosphide compounds, which render them a highly effective suicide method even in small quantities. Similar increases in phosphide-related suicides have been reported in Egypt and other low- and middle-income countries where regulatory control of highly hazardous pesticides remains limited [3,7-9]. The predominance of metal phosphide over other toxic agents underscores a shift toward more fatal means of self-harm rather than a diversification of suicide methods, with important implications for prevention and policy.

The distribution shows a marked predominance of young adults, particularly those in the third decade of life, indicating a high-risk age group for suicide by metal phosphide poisoning. Rural residence and low socioeconomic status were significantly overrepresented, underscoring the influence of agricultural accessibility and socioeconomic stressors on exposure risk. Sex distribution showed no significant difference, suggesting comparable vulnerability across genders when highly lethal toxicants are readily available [8].

Strict adherence to specimen handling protocols, including separate collection and airtight containment of multiple visceral samples, was critical to minimizing phosphine loss and cross-contamination. These factors are well-recognized sources of analytical error in forensic phosphide investigations [7–10]. The uniform classification of all cases as suicide reflects a comprehensive evaluation integrating circumstantial evidence, autopsy findings, and toxicological results, in accordance with accepted international standards of forensic practice [7,11]. In regions where metal phosphides remain readily accessible, such methodological rigor is necessary not only for legal adjudication but also for the integrity of epidemiological surveillance and public health reporting [3,12].

The autopsy findings observed—most notably petechial hemorrhages, pulmonary edema, and visceral congestion—are consistent with the established pathophysiology of phosphine toxicity. Phosphine induces severe cellular hypoxia through inhibition of mitochondrial oxidative phosphorylation, resulting in endothelial injury, increased vascular permeability, and acute cardiopulmonary failure [1,6,13]. The detection of a garlic-like odor in approximately half of the cases provided supportive evidence of exposure;

however, its inconsistent presence confirms its limited diagnostic value and reinforces the necessity of laboratory confirmation. The small proportion of cases lacking significant gross findings further illustrates the nonspecific nature of autopsy appearances in phosphide poisoning and the risk of under recognition in the absence of toxicological analysis.

A stable predominance of young adults in the third decade of life was observed throughout the study period, across both sexes and residential settings. This finding identifies early adulthood as the principal demographic group affected by suicide via metal phosphide poisoning and is consistent with Egyptian and regional forensic literature (3–5,7,8). This age group is frequently characterized by heightened psychosocial stressors, occupational exposure, and easier access to agricultural pesticides, factors that collectively increase vulnerability to fatal self-poisoning. The notable contribution of the second decade, particularly in specific years, carries important medico-legal implications, as adolescent and young adult deaths often require careful differentiation between accidental exposure and intentional ingestion, especially in rural contexts with inadequate pesticide storage and regulatory oversight [10-11].

Although descriptive differences between males and females were observed across age strata and seasons, pooled analysis did not demonstrate a significant overall association between age decade and sex. This finding supports previous observations that accessibility and lethality of phosphide compounds exert a stronger influence on suicide patterns than demographic characteristics alone [7,8]. Seasonal analysis revealed a statistically significant sex-related variation, with female predominance during autumn and spring and higher male representation during summer and winter. Comparable seasonal trends have been reported in Egyptian and international studies and may reflect agricultural cycles, climatic stressors, and sociocultural determinants influencing suicidal behavior [14,15].

CONCLUSIONS

Suicide by metal phosphide poisoning in Asyut Governorate predominantly affects young adults, with a consistent concentration of cases in the third decade of life across sexes, seasons, and residential settings. These findings emphasize the medico-legal importance of applying an integrated investigative framework when evaluating suspected metal phosphide poisoning deaths, and highlight the urgent need for stricter regulation of metal phosphide compounds, improved safe-storage practices, and targeted mental health interventions focusing on young adults in both urban and rural communities

Declarations

Ethics Approval and Consent to Participate

Approved by the Forensic Medicine Authority (FMA), Egypt, in accordance with the Declaration of Helsinki. Informed consent was waived due to the retrospective use of anonymized medico-legal and autopsy records.

Conflict of Interest

The authors declare no conflict of interest.

Acknowledgments

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Highlights

- Metal phosphide was the leading suicide method
- Young adults were most affected
- Autopsy findings reflected phosphine cardiopulmonary toxicity
- Cases increased significantly from 2021–2024
- Rural and seasonal patterns indicate preventable risks

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