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EFFICACY OF HYDROGEN CYANIDE FUMIGATION AGAINST TRIBOLIUM CONFUSUM AT A WHEAT MILL IN GORJ ROMANIA

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Abstract. *The phase-out of methyl bromide and the growing resistance of stored-product pests to phosphine have intensified the need for alternative fumigants in structural pest control. This study investigates the efficacy of hydrogen cyanide (HCN) as a viable alternative, with a specific focus on its application in a wheat mill located in Gorj County, Romania. The primary objective is to assess the performance of HCN fumigation against Tribolium confusum, a major pest species in stored grain environments, across all life stages. Current literature identifies HCN as a promising, fast-acting fumigant, yet field data under real-world mill conditions remain limited. This research addresses that gap through an in-situ application, incorporating gas monitoring, environmental analysis, and mortality assessment. Materials and methods include the use of calibrated detection equipment, sealing assessments, and post-fumigation inspection to validate outcomes. Results showed 100% mortality of larval and adult stages despite challenges such as wind interference and partial structural leakage, highlighting both the efficacy and sensitivity of HCN performance to environmental and infrastructural variables. The novelty of this study lies in its field-scale application in Eastern Europe, offering rare data under operational conditions. Limitations include localized environmental variables and the need for follow-up on residual stages. The findings support HCN's relevance as a potent alternative to conventional fumigants, with significant implications for pest management protocols in grain-processing facilities.*

Keywords: *Hydrogen cyanide fumigation, Tribolium confusum, stored-product pest control, grain mill fumigation, fumigant alternatives, pest resistance management, structural fumigation efficacy.*

INTRODUCTION

The management of pests in stored grain products is a critical concern for the agricultural industry, as infestations can lead to significant economic losses and compromise food security (BADGUJAR, SWAMINATHAN AND GERKEN, 2024; CHUANYANG ET AL, 2024; RETHORE, SHARMA AND KUMAR, 2022). Varius strategies are employed to mitigate these threats. However, challenges have emerged, including the development of pest resistance to phosphine and the environmental hazards associated with methyl bromide, necessitating the exploration of alternative solutions (NAYAK AND RAJESWARAN, 2024; HUI-YAN ET AL, 2024; GOTZE ET AL, 2022; FIELDS AND WHITE, 2002; ZETTLER AND ARTHUR, 2000, SPILIOTIS AND MITREA, 2000). Hydrogen cyanide (HCN), commercially known as BLUEFUME® (Draslovka Holding A.S., Czech Republic), has emerged as a promising alternative due to its high toxicity to a broad spectrum of insect pests and its rapid action (CHAYAPRASERT AND MAIER, 2024). HCN, commercially known as BLUEFUME®, has garnered attention as a promising alternative due to its high toxicity to a broad spectrum of insect pests and its rapid action. Its efficacy as a fumigant has been recognized in various countries, including the United States, Germany, the Czech Republic, South Korea, France, and Switzerland. HCN has demonstrated effectiveness against pests such

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as F*iorina externa*, *Lasioderma serricorne* and *Ips typographus* (CHASTAGNER ET AL, 2022; EDDE AND PHILLIPS, 2022; HNATEK ET AL, 2021).

Existing studies on the efficacy of BLUEFUME™ in controlling warehouse insects including *Tribolium confusum* are limited. Some research has demonstrated its potential in achieving high mortality rates among stored-product pests (AULICKÝ ET AL, 2015; AULICKÝ ET AL, 2015). For instance, certain studies have reported that HCN could effectively control insect populations resistant to other fumigants (ZETTLER AND ARTHUR, 2000). Similarly, research has highlighted HCN's effectiveness in conditions where traditional fumigants have failed, positioning it as a prominent alternative to existing fumigants (RAMBEANU ET AL, 2001). Despite these findings, there remains a significant gap in comprehensive field data and scientific literature regarding the practical application and efficacy of HCN, particularly under varying environmental conditions and against different pest species.

This study aims to address this gap by evaluating the efficacy of BLUEFUME® in a real-world setting—a grain mill of 16.500cm in Gorj County, Romania. The primary objective is to assess the effectiveness of HCN fumigation against *Tribolium confusum*, a common pest in stored grain products, across all developmental stages. Additionally, the study examines the influence of environmental factors, structural integrity, and fumigation protocols on the outcomes, thereby providing valuable insights for the integration of HCN into pest management strategies.

MATERIAL AND METHODS

The fumigation process was conducted over five days in June 2024 at a grain mill in Târgu Jiu. The mill is a six-story brick building divided into four sections: cleaning with grain bins, technological milling, flour storage silos, and dispatching with a packaging line. Preparation involved sealing the building, cleaning technological parts, and installing distribution lines for the fumigant.

Sealing was achieved using plastic or paper tapes combined with polyethylene (PE) foil to cover larger openings, while polyurethane (PUR) foam or silicone secured the foil. Ventilation outlets on the roof were sealed with PE foil attached to ducts using stretch foil and paper tapes. All products and raw materials were removed from treated areas, and flour storage silos were emptied. Grain silos, being full, were isolated and treated separately with phosphine gas. The technology was cleaned of product and grain residues, and components were opened to allow gas penetration.

Two distribution lines were installed using PE hoses (12/9 mm) with push-in fittings. After installation, a pressure test with process air at 6.0 bar ensured integrity. UniJet nozzles were attached, and functionality was verified through an "empty" test, checking for pressure drops. The lines were inerted with nitrogen before application to prevent premature reactions.

BLUEFUME® application dosage of 10gr/m³ was used as per biocides authorization in Romania. The total amount of BLUEFUME® required was calculated based on the building's external dimensions, with 165 kg prepared for application. The application commenced at 15:30 on June 14, 2024, following the manufacturer's guidelines, and concluded at 16:45. Post-application, distribution lines were purged with nitrogen to remove residual liquid. During the 24-hour exposure period, HCN concentrations were monitored at 10 sampling points using a Gasmet DX4040 (Gasmet Technologies Oy , Finland) with an automatic sampling path switcher and Riken Keiki FI-8000 (Riken Keiki Co., Ltd, apan)

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devices. Measurements were taken at various heights and locations, including basements and multiple floors, to assess gas distribution.

Environmental conditions were recorded using Testo 176 (Testo SE & Co. KGaA, Germany) dataloggers placed on the first floor, measuring temperature and relative humidity throughout the exposure period. Ventilation began at 16:00 on June 15, 2024. Initial steps included removing PE foils from air outlets, opening entrance doors, and activating the main electricity supply. HVAC ventilators were manually started, and all windows and doors were opened to facilitate aeration. Distribution lines were connected to process air to expedite desorption of HCN from PE hoses. Concentration levels around the building were monitored during this process to ensure safety. The efficacy of the fumigation was assessed using bioassays with *Tribolium confusum* at different developmental stages: eggs, larvae (3rd-4th instar), and adults. Test specimens were placed in plastic containers with plain flour and covered with breathable fabric. A total of 22 containers were used in the treatment, with 2 control containers. Each container held 20 adults and 20 larvae, totaling 480 adults and 480 larvae. Post-fumigation, mortality rates were evaluated within 24 hours for larvae and adults, and after 21 days for hatched larvae from eggs.

RESULTS AND DISCUSSIONS

During the fumigation process, hydrogen cyanide (HCN) concentrations were systematically monitored at ten sampling points within the mill to assess gas distribution and identify potential leakage areas. (Figure 1) Initially, concentrations aligned with the targeted dosage of 10 g/m³. However, a significant decline was observed within the first few hours of exposure, with concentrations dropping below 10 g/m³. The cumulative concentration-time product (CTP) was calculated by summing individual hourly concentration measurements over a 24-hour period, resulting in final CTP values ranging from 59 to 140 g·h/m³—considerably less than the labeled HCN rate of 240 g·h/m³. (Figure 2).

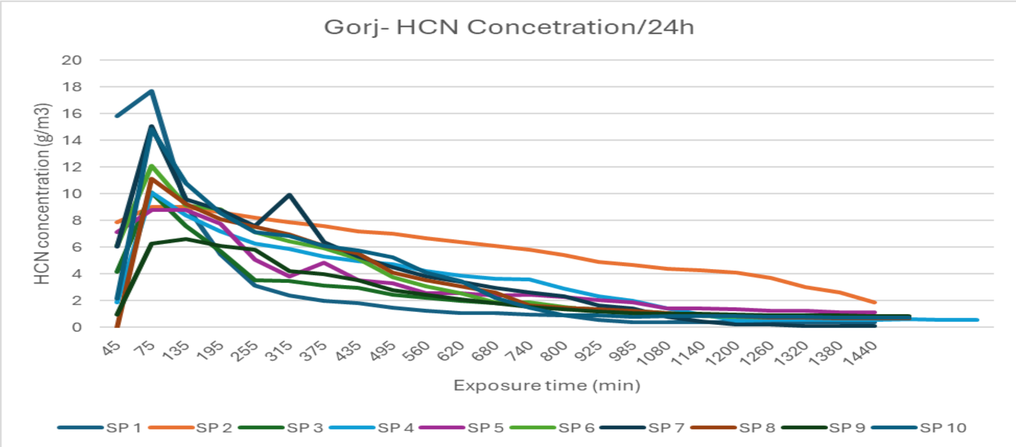

Figure 1. Measurements of HCN concentration every 60 minutes throughout the fumigation process across 10 sampling points, indicating the increase during HCN distribution and the gradual decrease after the cessation of liquid distribution. (SP1: mill's basement, SP2: grain silo basement, SP3: flour silo basement, SP4: first-floor flour silos, SP5: first-floor cleaning section, SP6: second-floor mill, SP7: third-floor cleaning section, SP8: fourth-floor milling section, SP9: sixth-floor flour silos, SP10: inside flour silos)

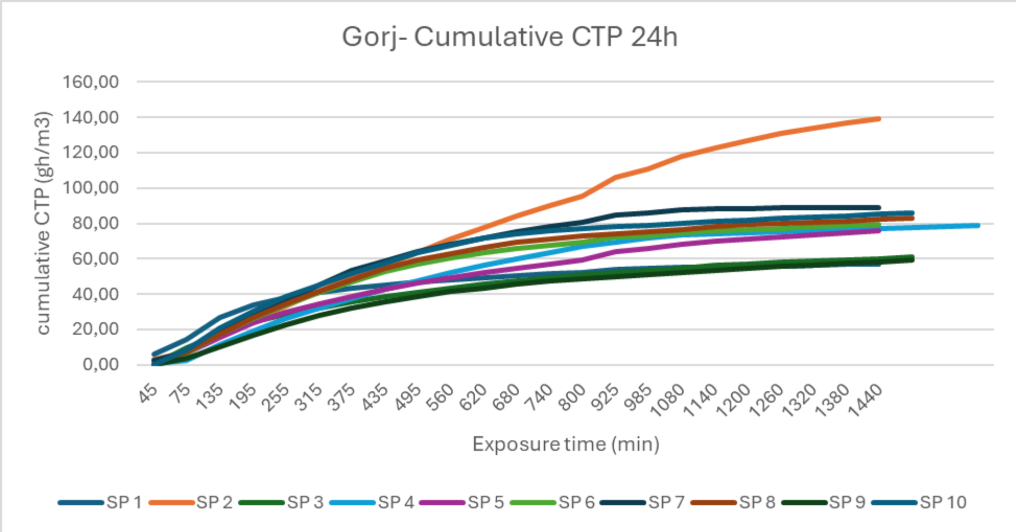

Figure 2. Cumulative concentration-time product (CTP) values at ten sampling points during fumigation. (SP1: mill's basement, SP2: grain silo basement, SP3: flour silo basement, SP4: first-floor flour silos, SP5: first-floor cleaning section, SP6: second-floor mill, SP7: third-floor cleaning section, SP8: fourth-floor milling section, SP9: sixth-floor flour silos, SP10: inside flour silos)

These findings underscore the critical importance of thorough sealing and consideration of environmental factors, such as weather conditions, during fumigation to maintain effective gas concentrations and ensure the efficacy of pest control measures. Implementing comprehensive sealing strategies and monitoring environmental conditions can mitigate gas loss and enhance fumigation effectiveness.

The experimental bioassays demonstrated a consistent 100% mortality rate for both adult and larval stages of *Tribolium confusum*, indicating the fumigant's maximum efficacy against these developmental stages (Table 1). This outcome aligns with previous studies that have reported high susceptibility of *T. confusum* adults and larvae to various fumigants, underscoring the effectiveness of such treatments in pest management strategies.

In contrast, the control bioassays (23 and 24) exhibited 0% mortality in adults and only 10% mortality in larvae, confirming that, in the absence of fumigation, the insects survived. Additionally, the high number of hatched eggs in the control samples (233 and 248) indicates that, without exposure to hydrogen cyanide (HCN), egg viability remains unaffected. These observations emphasize the critical role of fumigation in effectively controlling *T. confusum* populations.

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Table 1

Biological test results evaluating the efficacy of hydrogen cyanide (HCN) treatment on various developmental stages of *Tribolium confusum* (adults, larvae, and eggs), with mortality assessed at 24 hours for adults and larvae, and at 21 days for eggs based on the number of hatched individuals.

Position	**Adults**	**Larvas**	**Eggs**
	Mortality (100%)		
1	100	100	0
2	100	100	0
3	100	100	0
4	100	100	0
5	100	100	0
6	100	100	0
7	100	100	0
8	100	100	0
9	100	100	0
10	100	100	0
11	100	100	0
12	100	100	0
13	100	100	0
14	100	100	0
15	100	100	0
16	100	100	0
17	100	100	0
18	100	100	0
19	100	100	0
20	100	100	0
21	100	100	0
22	100	100	0
23-Control	0	10	233
24- Control	0	10	248

While the fumigant demonstrated complete lethality towards adults and larvae, its efficacy on *T. confusum* eggs was not directly assessed in this experiment. Previous research suggests that insect eggs can exhibit varying levels of resistance to fumigants, potentially requiring higher dosages or extended exposure periods to achieve complete mortality. Therefore, further investigation into the impact of fumigation on *T. confusum* eggs is recommended to optimize pest control strategies across all developmental stages.

Throughout the exposure period, temperature and relative humidity were consistently recorded on the first floor to ensure optimal conditions for hydrogen cyanide (HCN) fumigation. The temperature remained stable, averaging around 26°C, while relative humidity fluctuated between 44% and 67%. These environmental conditions are within acceptable ranges for HCN fumigation, as the effectiveness of HCN is influenced by factors such as temperature and humidity. Maintaining appropriate temperature and humidity levels is crucial to ensure the fumigant's potency and to prevent any potential degradation or reduced effectiveness. By carefully monitoring and controlling these parameters, the fumigation process can achieve optimal results, ensuring comprehensive pest eradication and maintaining the integrity of the treated environment.

The rapid decline in HCN concentrations observed during the fumigation process, particularly in specific areas of the mill, suggests potential issues with structural integrity and the effectiveness of sealing measures. Despite comprehensive sealing efforts using materials such as plastic tapes, polyethylene (PE) foils, and polyurethane (PUR) foam, certain sections may have been more susceptible to gas leakage. This susceptibility could be attributed to structural complexities or environmental factors like wind, which can exacerbate leakage.

These findings highlight the necessity for meticulous inspection and reinforcement of sealing measures, especially in older or architecturally complex structures. Ensuring robust

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sealing is crucial to prevent fumigant escape and to maintain uniform gas distribution, thereby enhancing the efficacy of the fumigation process.

The 100% mortality rate achieved with BLUEFUME® underscores its potential as a viable alternative to traditional fumigants such as phosphine and methyl bromide. The increasing concern of phosphine resistance among pests and the environmental restrictions placed on methyl bromide due to its ozone-depleting properties have necessitated the search for effective substitutes. HCN, the active component in BLUEFUME®, offers a rapid mode of action and broad-spectrum efficacy, positioning it as a promising candidate for integrated pest management strategies. However, to maximize its effectiveness, it is essential to consider factors such as application methods,prevailing environmental conditions, and the structural integrity of treatment facilities. Ensuring thorough sealing of structures and monitoring environmental parameters can enhance the uniform distribution and potency of HCN during fumigation processes.

CONCLUSIONS

This study demonstrates the high efficacy of BLUEFUME® (hydrogen cyanide) fumigation in achieving complete mortality across all developmental stages of *Tribolium confusum* in a grain mill setting. The findings highlight the importance of maintaining structural integrity and optimal environmental conditions to ensure effective fumigant distribution and retention. While HCN presents a promising alternative to traditional fumigants, further research is recommended to explore its efficacy against a broader range of pest species and under varying environmental conditions. Additionally, developing standardized protocols for sealing and application can enhance its practical implementation in diverse storage facilities.

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