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EVALUATION OF STRUCTURAL HEAT TREATMENT FOR THE CONTROL OF TRIBOLIUM CASTANEUM IN A COMMERCIAL WHEAT MILL IN SOUTHERN ROMANIA

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ABSTRACT

This study evaluated the effectiveness of structural heat treatment against Tribolium castaneum in a commercial wheat mill located in Giurgiu County, Romania. Thirty-five electric heaters (700 kW in total) and 17 temperature data loggers were used. Bioassays with eggs, larvae, and adults were placed at 11 locations, with one untreated control. Heating lasted 54 h, and temperatures were maintained for approximately 20 h after the coldest monitored point reached 50 °C. Mortality was at least 95 % at all locations. Survival ranged from 0 to 5.0 % for larvae and adults and from 1.2 to 4.5 % for eggs, with higher survival generally observed in the silo area and on lower floors. This pattern suggests that heat distribution within the facility influenced treatment efficacy. Structural heat treatment is an effective non-chemical component of integrated pest management in commercial wheat mills.

INTRODUCTION

The red flour beetle, *Tribolium castaneum*, is one of the most economically important insect pests associated with stored cereals and cereal-processing facilities worldwide. The species is frequently encountered in flour mills, feed mills, grain storage facilities, and food-processing environments, where it exploits flour residues, grain dust, and protected structural refuges for reproduction and survival (Gao et al. 2022). Infestations can result in substantial economic losses through product contamination, quality deterioration, reduced market value, and increased costs associated with sanitation and pest management programs (Paul et al. 2020). Traditionally, the management of *Tribolium castaneum* populations in milling facilities has relied heavily on chemical control methods, particularly phosphine fumigation. However, the widespread development of phosphine resistance, combined with increasing concerns regarding worker safety, environmental protection, and consumer demand for residue-free products, has encouraged the adoption of alternative pest management strategies (Paul et al. 2020, Gao et al. 2022).

Among these alternatives, structural heat treatment has emerged as one of the most effective methods for controlling insect infestations in food-processing

facilities. Structural heat treatment involves elevating the ambient temperature of a building to approximately 50–60 °C for a sufficient period to achieve mortality of all insect developmental stages (Beckett & Fields 2007, Subramanyam et al. 2011). Unlike chemical fumigation, heat treatment leaves no toxic residues, reduces facility downtime, and can be incorporated into sustainable pest management programs (Sakka et al. 2022).

The effectiveness of heat treatment depends on several factors, including maximum temperature attained, exposure duration, heating rate, facility design, and the presence of cold spots within the structure (Kang et al. 2020, Sakka et al. 2022). Previous studies conducted in pilot flour mills demonstrated that eggs, larvae, pupae, and adults differ in their susceptibility to elevated temperatures, emphasizing the importance of monitoring multiple developmental stages during commercial heat treatments (Brijwani et al. 2012b, Kang et al. 2020). In addition, insect mortality is influenced not only by peak temperatures but also by cumulative thermal exposure, making continuous temperature monitoring essential for identifying locations where insects may survive (Porto et al. 2017, Sakka et al. 2022). Areas protected by machinery, insulation materials, wall cavities, or flour accumulations may remain below lethal temperature thresholds and serve as refuges for surviving insects (Porto et al. 2017). Recent investigations in commercial milling facilities have confirmed that treatment success is strongly associated with achieving and maintaining target temperatures throughout the structure (Sakka et al. 2022).

Different developmental stages of *Tribolium castaneum* exhibit varying levels of thermal tolerance, with eggs and larvae often reported as the most heat-tolerant stages and therefore widely used as biological indicators during commercial heat treatments (Kang et al. 2020, Gao et al. 2022). The use of bioassays placed at selected locations within processing facilities provides valuable information regarding treatment efficacy under operational conditions and allows direct assessment of mortality in relation to local temperature profiles (Sakka et al. 2022).

Although structural heat treatment has been extensively investigated in North America and Australia, information regarding its application in commercial wheat mills in Eastern Europe remains limited. Furthermore, no published studies have evaluated the effectiveness of thermal dezinsection against *Tribolium castaneum* under commercial milling conditions in Romania. Therefore, locally generated data are needed to improve understanding of temperature distribution patterns and insect mortality during heat treatments performed in Romanian facilities. The objective of this study was to evaluate the effectiveness of structural heat treatment against *Tribolium castaneum* in a commercial wheat mill located in the Giurgiu area of Romania. Temperature profiles were continuously monitored throughout the heating process, while bioassays containing eggs, larvae, and adults of *Tribolium castaneum* were placed at selected locations within the mill. The relationship between thermal exposure and stage-specific mortality was assessed in order to provide practical recommendations for optimizing heat-treatment protocols and improving integrated pest management programs in Romanian wheat-processing facilities.

MATERIAL AND METHODS

The study was conducted in a commercial wheat mill located in Giurgiu County, southern Romania, between 30 April and 3 May 2026. The treated facility had an approximate volume of 5,000 m^3 and consisted of a ground floor, five

production floors, and an adjacent grain silo section (Figure 1). Prior to treatment, standard sanitation procedures were performed as part of the mill's routine pest management program.

Structural heat treatment was carried out using 35 electric heaters (20 kW each), providing a total installed heating capacity of 700 kW (Figure 2). All heaters were connected to the facility's central electrical distribution board (Figure 3) and operated continuously throughout the treatment period. The heating system was arranged to promote uniform heat circulation throughout the mill (Figure 4). The treatment consisted of an active heating and exposure phase lasting 54 h, followed by a cooling phase of approximately 12 h. The target treatment temperature was 50 °C, and exposure was maintained for approximately 20 h after the coldest monitored point within the facility reached this temperature.

Temperature distribution during the treatment was monitored using 17 EL-WIFI-DTC temperature data loggers (Figure 5; Lascar Electronics Ltd., Salisbury, United Kingdom). The sensors were distributed throughout the facility to represent the principal structural zones of the mill, including the ground floor, production floors, and silo section. Temperature measurements were recorded automatically at 30-min intervals from the beginning of the heating phase until the end of the exposure phase. Six sensors were installed on the ground floor, three on the first floor, two on the second floor, one on the third floor, two on the fourth floor, two on the fifth floor, and one in the silo section.

The efficacy of the heat treatment was evaluated using bioassays containing different developmental stages of *Tribolium castaneum*. Test insects originated from laboratory colonies maintained under controlled environmental conditions of 23–25 °C and 50–60 % relative humidity. Egg bioassays were prepared by allowing adults to oviposit in sifted flour. Eggs aged 24–48 h were collected and transferred into plastic containers containing a thin layer of flour, with each bioassay containing approximately 200–250 eggs; the exact number of eggs in each bioassay was counted and recorded at the time of setup. Larval and adult bioassays consisted of perforated plastic containers (8 cm diameter) containing wheat flour and covered with breathable fabric (Figure 6). Each container contained 20 third- to fourth-instar larvae and 20 adults.

A total of 11 treatment bioassays and one untreated control bioassay were used. Bioassays were installed immediately before the start of heating and were collected following completion of the treatment and cooling phase. Following retrieval, egg bioassays were incubated for 21 d at 29 °C, 65 % relative humidity, and a 14:10 h light: dark photoperiod prior to hatch assessment. Larval and adult mortality were assessed 24 h after retrieval of the bioassays at the end of the treatment and cooling phase, by directly counting live and dead individuals in each container. Mortality observed in treated bioassays was compared with that recorded in the untreated control.

Temperature data recorded by the EL-WIFI-DTC data loggers were downloaded and processed using EasyLog Cloud software (Lascar Electronics Ltd., Salisbury, United Kingdom) and Microsoft Excel (Microsoft Corporation, Redmond, WA, USA). For each sensor, the minimum and maximum temperatures recorded during the treatment and the cumulative duration (h) at or above the 50°C target were determined. Survival and mortality percentages were calculated separately for larvae (alive/20), adults (alive/20), and eggs (hatched/initial number of eggs recorded for that bioassay) of *Tribolium castaneum* for each bioassay location.

Treatment efficacy was evaluated by comparing mortality in exposed bioassays with that observed in the untreated control. Because control mortality was below 5 % for all life stages (0 % for larvae and adults and 2.4 % for eggs), treatment mortality was not corrected using Abbott's formula (Abbott 1925). Because each treatment location was represented by a single bioassay without within-location replication, survival data are presented descriptively and no inferential statistical comparison among locations was performed.

Before the start of heating, treatment bioassays were placed at locations representing major processing and product-transfer areas of the mill, including the silo section, cleaning equipment, elevator systems, milling machinery, plansifter section, flour filtration system, and product transfer lines. One untreated control bioassay was kept in an untreated room of the mill throughout the experiment. The distribution of bioassays within the facility is shown in Table 1 and Figure 7.

Table 1

Locations of *Tribolium castaneum* bioassays used to evaluate the efficacy of structural heat treatment in the wheat mill.

Bioassay ID	Location within the mill
1	Conveyor belt located beneath the wheat silos
2	Inside an empty wheat silo
3	Base of bucket elevator (ground floor)
4	Grain cleaning section (ground floor)
5	Grain crushing/roller milling unit (first floor)
6	Cleaning section (first floor)
7	Product transfer piping system (second floor)
8	Drive motor area (second floor)
9	Plansifter section (third floor)
10	Flour filter unit (fourth floor)
11	Product transfer pipes with inspection windows (fifth floor)
12	Untreated control kept in an untreated room of the mill



Figure 1. General view of the wheat mill facility subjected to structural heat treatment. (Original)



Figure 2. Example of heater placement within the mill. (Original)

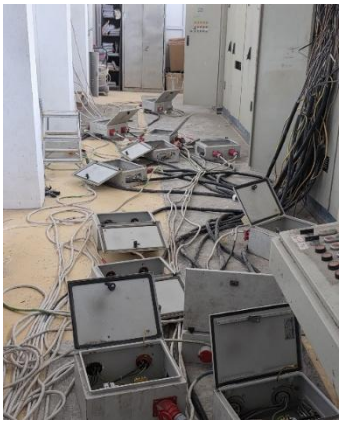


Figure 3. Electrical heaters connected to the central power distribution panel during structural heat treatment. (Original)



Figure 4. Air circulation fan used to improve heat distribution during structural heat treatment. (Original)



Figure 5. EL-WIFI-DTC temperature data logger installed within the wheat mill during structural heat treatment. (Original)



Figure 6. *Tribolium castaneum* bioassay containers. (Original)



Figure 7. Placement of *Tribolium castaneum* bioassays within the wheat mill. (Original)

RESULTS AND DISCUSSIONS

Structural heat treatment resulted in high mortality of *Tribolium castaneum* at all monitored locations within the wheat mill. At 24 h after retrieval of the bioassays at the end of the treatment and cooling phase, only a small number of larvae and adults survived in the treated bioassays, whereas survival in the untreated control remained close to 100 % (Table 2).

Table 2

Survival of *Tribolium castaneum* life stages following structural heat treatment.

Bioassay ID	Location	Larvae alive/20	Adults alive/20	Eggs hatched/initial	Larvae survival (%)	Adult survival (%)	Egg hatch (%)
1	Conveyor belt beneath silos	1	1	9/231	5.0	5.0	3.9
2	Empty silo	1	1	10/248	5.0	5.0	4.0
3	Base of bucket elevator (ground floor)	1	1	11/247	5.0	5.0	4.5
4	Grain cleaning section (ground floor)	1	1	11/243	5.0	5.0	4.5
5	Roller milling unit (first floor)	1	0	8/236	5.0	0.0	3.4
6	Cleaning section (first floor)	1	0	8/210	5.0	0.0	3.8
7	Product transfer piping system (second floor)	0	1	6/204	0.0	5.0	2.9
8	Drive motor area (second floor)	0	1	5/225	0.0	5.0	2.2
9	Plansifter section (third floor)	0	1	5/224	0.0	5.0	2.2
10	Flour filter unit (fourth floor)	0	1	4/204	0.0	5.0	2.0
11	Product transfer pipes (fifth floor)	0	0	3/246	0.0	0.0	1.2
12	Untreated control	20	20	242/248	100.0	100.0	97.6

The highest survival was observed in bioassays placed in the silo area and on the ground floor, whereas the lowest survival occurred on the upper floors of the mill. Egg hatch, calculated against the initial number of eggs in each bioassay, followed a similar pattern, ranging from 1.2 to 4.5 % in treated bioassays. Overall mortality was at least 95 % at all treatment locations.

Mean survival in treated bioassays was 2.7 % for larvae (mean mortality 97.3%), 3.6 % for adults (96.4 %), and 3.2 % for eggs (96.8 %). Survival tended to decrease from the silo area and lower floors toward the upper floors of the mill; because each location was represented by a single bioassay, this trend is described qualitatively and was not tested statistically.

The observed distribution of survival likely reflects differences in heat circulation within the facility. Similar observations have been reported during pilot-scale flour mill heat treatments, where sanitation levels, equipment configuration, and localized cold spots influenced insect survival (Brijwani et al. 2012a). Warm air naturally rises through the structure, resulting in greater heat accumulation on the upper floors, whereas locations near machinery, elevator bases, and enclosed spaces may heat more slowly and function as temporary thermal refuges (Mahroof et al. 2003, Porto et al. 2017).

Temperature records were consistent with this pattern (Table 3). Sensors on the second to fifth floors reached maximum temperatures of 63.7–66.3 °C and remained at or above 50 °C for 35.0–38.0 h, and first-floor sensors for 31.0–34.5 h

(maximum 59.9–62.1 °C). In contrast, ground-floor sensors reached 59.1–60.2 °C and remained at or above 50 °C for only 24.5–29.0 h, while the silo sensor, which also recorded the lowest initial temperature (8.2 °C), showed the shortest exposure (23.5 h). The locations with the shortest durations above 50 °C, the silo section and ground floor, corresponded to those where survival in Table 2 was highest.

Table 3

Location of the 17 EL-WIFI-DTC sensors, minimum and maximum temperatures recorded, and cumulative time at or above the 50 °C target during structural heat treatment.

Sensor ID	Location	Min. (°C)	Max. (°C)	≥ 50 °C (h)	Sensor ID	Location	Min. (°C)	Max. (°C)	≥ 50 °C (h)
1	Ground floor	13.0	59.1	24.5	10	Second floor	16.1	64.0	35.0
2	Ground floor	13.2	60.0	28.0	11	Second floor	16.5	63.7	35.5
3	Ground floor	13.5	60.2	27.5	12	Third floor	17.7	64.3	35.0
4	Ground floor	13.1	60.2	28.0	13	Fourth floor	19.2	65.5	35.5
5	Ground floor	13.2	59.2	28.5	14	Fourth floor	19.4	65.6	35.0
6	Ground floor	13.3	60.0	29.0	15	Fifth floor	20.1	66.3	37.5
7	First floor	14.6	59.9	31.0	16	Fifth floor	20.3	65.9	38.0
8	First floor	14.9	62.1	34.5	17	Silo section	8.2	59.8	23.5
9	First floor	15.0	61.2	33.0					

Despite the presence of a small number of survivors, mortality was at least 95 % at all treatment locations, demonstrating the high efficacy of structural heat treatment against *Tribolium castaneum*. The results are comparable to those reported by Brijwani et al. (2012b) and Sakka et al. (2022), who observed high levels of mortality of *Tribolium* spp. during commercial heat treatments. Maintaining the treatment for approximately 20 h after the coldest monitored point reached 50 °C likely contributed to the overall effectiveness of the procedure.

Overall, the findings indicate that structural heat treatment is an effective non-chemical method for suppressing *Tribolium castaneum* populations in commercial wheat mills, supporting previous reports that heat treatment can serve as an important component of integrated pest management programs in grain-processing facilities (Subramanyam et al. 2011). However, the occurrence of limited survival in certain locations highlights the importance of combining heat treatment with effective sanitation and post-treatment monitoring.

CONCLUSIONS

Structural heat treatment proved to be an effective non-chemical method for the control of *Tribolium castaneum* in a commercial wheat mill in southern Romania. The treatment achieved mortality levels of at least 95% across all monitored locations, demonstrating the ability of elevated temperatures to substantially reduce populations of this important stored-product pest. Although limited survival was observed in some lower-level and silo locations, likely due to localized differences in heat distribution, overall efficacy remained high throughout the facility. These findings indicate that structural heat treatment can serve as a practical alternative to chemical fumigation in wheat-processing facilities, particularly when combined with

effective sanitation measures and routine pest monitoring as part of an integrated pest management program.

REFERENCES

Abbott W. S. 1925. A method of computing the effectiveness of an insecticide. Journal of Economic Entomology, 18, 265-267. DOI: https://doi.org/10.1093/jee/18.2.265a

Beckett S. J., Fields P. G. 2007. Disinfestation of stored products and associated structures using heat. In: Heat Treatments for Postharvest Pest Control. CAB International, Wallingford, United Kingdom, pp. 182-237.

Brijwani M., Subramanyam B., Flinn P. W. 2012a. Impact of varying levels of sanitation on mortality of *Tribolium castaneum* eggs and adults during heat treatment of a pilot flour mill. Journal of Economic Entomology, 105, 703-708. DOI: https://doi.org/10.1603/EC11343

Brijwani M., Subramanyam B., Flinn P. W., Langemeier M. R., Hartzer M., Hulasare R. 2012b. Susceptibility of *Tribolium castaneum* life stages exposed to elevated temperatures during heat treatments of a pilot flour mill: influence of sanitation, temperatures attained among mills floors, and costs. Journal of Economic Entomology, 105, 709-717. DOI: https://doi.org/10.1603/EC11114

Gao F., Qi Y., Hamadou A. H., Zhang J., Manzoor M. F., Guo Q., Xu B. 2022. Enhancing wheat-flour safety by detecting and controlling red flour beetle *Tribolium castaneum* Herbst (Coleoptera: Tenebrionidae). Journal of Consumer Protection and Food Safety, 17, 113-126. DOI: https://doi.org/10.1007/s00003-022-01371-3

Kang Y., Lyu J., Wang P. 2020. The influence of different heating rates on mortality of *Tribolium castaneum* (Herbst) (Coleoptera: Tenebrionidae). Grain & Oil Science and Technology, 3, 64-69. DOI: https://doi.org/10.1016/j.gaost.2020.03.001

Mahroof R. M., Subramanyam B., Eustace D. 2003. Temperature and relative humidity profiles during heat treatment of mills and its efficacy against *Tribolium castaneum* life stages. Journal of Stored Products Research, 39, 555-569. DOI: https://doi.org/10.1016/S0022-474X(02)00062-0

Paul A., Radhakrishnan M., Anandakumar S., Shanmugasundaram S., Anandharamakrishnan C. 2020. Disinfestation techniques for major cereals: A status report. Comprehensive Reviews in Food Science and Food Safety, 19, 1125-1155. DOI: https://doi.org/10.1111/1541-4337.12555

Porto S. M. C., Valenti F., Bella S., Russo A., Cascone G., Arcidiacono C. 2017. Improving the effectiveness of heat treatment for insect pest control in flour mills by thermal simulations. Biosystems Engineering, 164, 189-199. DOI: https://doi.org/10.1016/j.biosystemseng.2017.10.015

Sakka M. K., Jagadeesan R., Nayak M. K., Athanassiou C. G. 2022. Insecticidal effect of heat treatment in commercial flour and rice mills for the control of phosphine-resistant insect pests. Journal of Stored Products Research, 99, 102023. DOI: https://doi.org/10.1016/j.jspr.2022.102023

Subramanyam B., Mahroof R. M., Brijwani M. 2011. Heat treatment of grain-processing facilities for insect management: A historical overview and recent advances. Stewart Postharvest Review, 7, 1-11. DOI: https://doi.org/10.2212/spr.2011.2.2