Storage of Cereals in Warehouses

Subjects: Agriculture, Dairy & Animal Science

Contributor: Anita Liška

Storage of Cereals in Warehouses refers to the methods of how people restore the cereals. In this entry, we depict the development history and basic storage information. For decades, the use of various synthetic pesticides has been the key factor in the proper and long-term storage of cereals. Unfortunately, we are faced with non-acceptable data regarding the effects of synthetic pesticides. Due to this, further steps have been made in order to take measures to reduce the use and risk of chemical pesticides by 50% by 2030 and to reduce the use of more dangerous pesticides by 50% by 2030. The concept of integrated pest management has been promoted as a dynamic and flexible approach leading to the reduction of chemical pesticide usage and their negative effects on the environment.

Storage of Cereals | Postharvest Losses | Storage Pests | Integrated Protection Measures

1. Introduction

Storing grain in warehouses is important for preserving the quantities produced and providing a sufficient amount of food for the population. Well-preserved cereals are vital for producers for obtaining a quality product in accordance with the properties of their culture, and for consumers to receive food products of a good quality. For the cultivation of crops in the field, farmers need to make significant financial investments and put in many hours of work; however, after the goods enter a warehouse, concerns regarding the loss of quality gradually decrease, so losses can occur and the quality and quantity of stored goods can also decrease.

2. Storing Cereals

During storage, the goal is to preserve the stored goods both quantitatively and qualitatively. If we exclude losses caused by natural changes such as the gradual drying of grain and respiration and other processes that contribute to a reduction of the quantity and quality, the most important aim is to protect goods from losses caused by microorganisms and storage fungi and pests.

Monitoring the change in heat of stored agricultural products and sampling is not always carried out systematically, which makes it difficult to know the true condition of stored cereals. In order to gain insight into the condition of stored cereals, it is necessary to take samples regularly, check the temperature of stored goods, and record data. Continuous temperature monitoring within stored grain is relatively easy using thermocouples. When an increase in temperature is observed, it can be assumed that the insect population is present or the existing one has started to grow and be more active. The present population of storage fungi can also cause an increase in the temperature of stored goods. However, by using available techniques, it is not easy to detect small insect or fungi populations [1].

Temperature is one of the key environmental factors affecting the physiological, life history, behavioral, and population processes of arthropods [2]. The largest increase in insect population occurs at optimal breeding temperatures ranging from 25 to 32 °C. Development is slowed down at temperatures ranging from 13 to 24 °C and 33 to 35 °C. Lethal temperatures are below 13 °C and above 35 °C, when insects stop feeding, development is slowed down, and insect death occurs. The more extreme the conditions, the faster the insects die [3]. However, the mentioned relationship between temperature and the developmental rate varies among different strains, species, and higher taxa [4]. In a recent review, Stejskal et al.[2] presented an extensive approach on stored pests and temperatures, with an emphasis on the lower development thresholds that define temperature zones for safe storage. Imura[5] estimated the insect lower temperature thresholds (LT) and degree-days (DD) required for egg to adult development for 51 stored products. The lowest LT = 6.9 and the highest DD = 1551.5 were obtained for *Hofmannophila pseudospretella* (Stainton), whereas the highest LT = 19.8 °C (lab) to 21.5 °C (Ghana) and the lowest DD = 319.4 to 286.6 were obtained for *Latheticus oryzae* (Waterhouse). Accordingly, for *Sitophilus granarius* (L.), LT = 10.5 °C and DD = 517.6, whereas for *Sitophilus oryzae* (L.), LT = 13.5 (13.6) °C and DD = 466.7 (422.1). The estimated values for *Tribolium confusum* (Jacq. du Val.) were LT = 17.8 (17.9) °C and DD = 334 (415.2), whereas those for *Tribolium castaneum* (Herbst) were LT = 10.5 °C and DD = 517.6.

Accordingly, it is best to store cereals at lower temperatures. However, due to environmental conditions, it is not always possible to achieve appropriate low temperatures.

In addition to the storage temperature, grain moisture is also important. It is certainly important to bring the driest grain into the warehouse, but if it is necessary to dry it due to a high level of grain moisture, this drying process should be done by gradually lowering the moisture; otherwise, sudden drying can cause the cracking of grain, reducing the quality and creating optimal conditions for storage pests and fungi. A grain moisture value from 13 to 14% is optimal for storing wheat and corn .

2.1. Storage

Cereals are stored in different types of storage. Large quantities of tens of thousands of tons are usually stored in concrete silos arranged in a row, and significant quantities are also stored in metal silos and warehouses. Smaller farms use smaller capacity silos, usually made of metal, which are adapted to the size of the farm and the quantities produced and required. On small farms, cereals are stored in various containers or handy warehouses according to production for their own needs.

It is important that grain is stored in a properly constructed warehouse. This means that, during storage, there is no wetting from the breathing of the grain, there are no openings in the concrete walls through which insects or rodents can enter, and that no wetting occurs during precipitation. Additionally, the grain temperature close to the wall changes with the season[6] [6]. Apart from in exceptional cases, silo compartments need not be specially protected for impermeability, such as through treatment with carbon dioxide or phosphine.

2.2. Risks Associated with Storage Pests

Stored-product insects can be found in the bulk storage of raw commodities, in processing facilities such as flour and feed mills, in food-manufacturing facilities and bakeries, and in all other structures employed for food product storage or transport[7]. When it comes to food safety and quality, high standards are priorities in most countries. Although Europe has mandated a zero tolerance for insect fragments in food, in real conditions, this is hardly fulfilled. According to the EU database named the Rapid Alert System for Food and Feed (RASFF), recent analysis[8] revealed that the top three reported foreign materials found in agricultural food products were arthropod pests (54.6%), glass fragments (17.4%), and metals (11.5%). Estimated postharvest losses caused by stored-product insects range from up to 9% in developed countries to 20% or more in developing countries [9]. Risks associated with storage pests are diversely manifested as direct physiological effects and indirect effects[9][10]. The most important direct effect is associated with the contamination of food by arthropod fragments, which can be carcinogenic or allergenic. Stored-product pests, mites, and insects produce a variety of chemical compounds that cause allergic reactions in humans and domestic pets [10][11][12]. Indirectly, stored pests change the moisture content and temperature of stored food, developing optimal conditions for the growth of pathogenic microorganisms[13], or they host and transmit microorganisms, including antibiotic-resistant strains[14][15].

The fact that stored pests affect the food quality and adversely affect human health at a deeper level means that extensive management within the integrated pest management (IPM) programs is a key element required for their control.

3. Integrated Protection Measures

Integrated protection measures give preference to mechanical, physical, and biological measures, but if the required effectiveness is not achieved, some of the permitted insecticides must be used. During application, it is important to take care that the combination of pest control measures is both economically and environmentally justified, and that the risk to humans and the environment is the lowest possible.

Today, there is more and more talk about banning any use of synthetic pesticides and ensuring that protection is only produced by applying measures that do not leave harmful residues. However, the question of what to do if these non-pesticidal measures cannot ensure an adequate effectiveness against pests arises. Who will bear the responsibility and consequences for the quantities and quality of goods in trade and processing?

The facts show that the application of mechanical, physical, and/or biological measures is very demanding because it requires more knowledge, better equipment, greater financial investment, and raising awareness not only among storekeepers and grain processors, but also among consumers.

3.1. Mechanical Measures

These measures are performed by employees in the silo or warehouse, and include cleaning the empty storage space of dust, insects, and various residues from previous commodities. It is best to use vacuum cleaners for this, and where possible, wash the surfaces. Cereals in the warehouse are often moved from one place to another, i.e., from one silo compartment to another, and when unloading, the impurities are removed by aspiration. This measure can reduce the number of damaged grains, remove insects from the grains, and eradicate other impurities more easily from healthy grain. Unfortunately, this procedure is not able to remove insects that live in the grain, and this can cause a problem during transport, as it is possible to see live insects emerging from the grain that have not been removed by aspiration at the final destination. Of course, the question of whether the buyer will accept to take over such goods or will return them to the sender or will request the performance of a countermeasure at the expense of the supplier at the place of delivery arises. Good sanitation measures generally represent a starting point for the success of integrated pest management programs. Morrison et al.[16] found that decreased sanitation negatively affected the efficacy of most tactics examined, with a mean 1.3–17-fold decrease in efficacy under poorer sanitation compared to better sanitation. Therefore, poor sanitation can result not only in refugia of insects in grain bins providing re-infestation, but can indirectly decrease the efficacy of biological measures[17], chemical control tactics [18], and modified atmosphere regimes [19].

3.2. Physical Measures

Physical measures that can be performed to protect against pests on stored cereals take into account different ways of cooling.

If the heat of the goods exceeds 18 °C, it is necessary to perform cooling by inserting cold air from the environment or cooled air or to transfer cereals from one silo compartment to another. It is important to maintain a low temperature and relative humidity in the storage and to ventilate when the air is dry and cold[20]. The cold air blower installed in the silo must be switched on until the heat of the goods is reduced at the top, i.e., until cold air penetrates to the top. Maintaining low temperatures in a warehouse or silo is essential because it slows down the development and activity of pests of stored cereals or storage fungi that are present [21]. Chilled cereals remain cold, even at higher outdoor temperatures, due to the poor thermal conductivity of cereals. Switching, which is most often done in silos, does not contribute to significant cooling due to the poor thermal conductivity [3]. If it is possible to choose between switching from compartment to compartment and injecting cold air with cooling devices, it is better to introduce cold air into the grain and reduce the damage. Without considering the difference in energy consumption for each procedure, switching has the advantage that aspiration can be switched on and various impurities, damaged grains, and insects can be removed. The performance of the cooling method significantly depends on an insect’s cold tolerance. Even life stages of individual species vary in susceptibility to cold [22]. It has been proven that some stored product insect pests were mobile at low temperatures (2.5 °C), while other species could not move until temperatures reached 10 °C or higher [23]. Another relevant factor of cooling grain as a physical method is the temperature decrease rate. Jian et al. [23] concluded that when grain inside bins is cooled rapidly, the movement of insects can be stopped at a higher temperature than that when grain is cooled gradually. The temperature fluctuation allows an opportunity for insects to adapt to low temperatures [23][24].

Heat treatment is another possibility of physical measures for insect control during storage. It can be implemented through different treatments: As solar heating; water-based and atmospheric heating; steam treatment; flame treatment; forced hot air treatment; electric field treatment; and high-temperature-controlled atmosphere treatment[25]. The target air temperature for effective disinfestation should be at least 50 °C[26][27]. Factors that affect success in heat treatments are the insect species [28], treatment duration [29], and life stages [30]. Additionally, several other aspects should be taken into consideration. Insects inside kernels are more protected than individuals outside the kernel. Therefore, with the treatment of 105 °C hot air, *S. oryzae* adults outside wheat kernels showed about two times greater mortality when compared with young adults inside wheat kernels [31]. The grain quality, especially the seed germination rate, could be greatly affected by high temperature treatment. The treatment required to reach 100% mortality of insects inside kernels caused a 20% drop in germination in steam and 81% drop in hot air [23]. Another relevant issue is maintaining a constant rate of temperature during the whole treatment exposure period regarding the specifics of a commodity’s nature and industry or storage facilities. The authors Porto et al. [27] developed a method to improve the effectiveness of heat treatment for insect pest control in flour mills by thermal analyses and temperature trend models, with specific attention being paid to surface temperatures of thermal bridges as heat treatment weakness points. Furthermore, there have been some advances in heat treatment techniques. For instance, the radio frequency as a dielectric heating-based technique is considered to have an improved efficacy compared with traditional heating techniques [32] due to its fast, volumetric, and deep penetration heating characteristics [33].

References

1. Communication From The Commission To The European Parliament, The European Council, The Council, The European Economic And Social Committee And The Committee Of The Regions The European Green Deal https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6691 (accessed on 12 Jul 2020)
2. EU Biodiversity Strategy for 2030. Available online: https://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm (accessed on 12 Jul 2020)
3. Communication from The Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions-A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0381&from=EN (accessed on 12 Jul 2020)
4. Jian, F.; Jayas, D.S. Temperature Monitoring. Available online: https://entomology.k-state.edu/doc/finished-chapters/s156-ch-23-temperature-monitoring.pdf (accessed on 23 October 2020).

5. Stejskal, V.; Vendl, T.; Li, Z.; Aulicky, R. Minimal thermal requirements for development and activity of stored product and food industry pests (Acari, Coleoptera, Lepidoptera, Psocoptera, Diptera and Blattodea): A review. Insects 2019, 10, 149, doi:10.3390/insects10050149.
6. Fields, P.; Subramanyam, B.; Hulasare, R. Available online: https://www.researchgate.net/publication/303249099_Extreme_temperatures (accessed on 13 July 2020).
7. Imura, O. Thermal requirements for development of stored-product insects. Tribolium Inf. Bull. 1990, 30, 58–68.
8. McKenzie, B.A.; Van Fossen, L. Managing Dry Grain in Storage Available online: https://www.extension.purdue.edu/extmedia/aed/aed-20.html (accessed on 23 October 2020).
9. Nayak, M.K.; Collins, P.J.; Holloway, J.C.; Emery, R.N.; Pavic, H.; Bartlet, J. Strong resistance to phosphine in the rusty grain beetle, Cryptolestes ferrugineus (Stephens) (Coleoptera: Laemophloeidae): Its characterisation, a rapid assay for diagnosis and its distribution in Australia. Pest Manag. Sci. 2013, 69, 48–53.
10. Gorham, J.R. Ecology and Management of Food Industry Pests; Assoc. Off. Anal. Chemists: Arlington, VA, USA, 1991; p. 595.
11. Djekic, I.; Jankovic, D.; Rajkovic, A. Analysis of foreign bodies present in European food using data from Rapid Alert System for Food and Feed (RASFF). Food Control 2017, 79, 143–149.
12. Phillips, T.W.; Throne, J.E. Biorational approaches to managing stored-product insects. Annu. Rev. Entomol. 2010, 55, 375–397.
13. Hubert, J.; Stejskal, V.; Athanassiou, C.G.; Throne, J.E. Health hazards associated with arthropod infestation of stored products. Annu. Rev. Entomol. 2018, 63, 553–573.
14. Fernandez-Caldas, E. On mite allergy in dogs and humans. Int. Arch. Allergy Immunol. 2013, 160, 329–330.
15. Erban, T.; Stejskal, V.; Aulicky, R.; Krizkova-Kudlikova, I.; Nesvorna, M.; Hubert, J. The influence of environmental temperature and humidity on temporal decomposition of cockroach allergens Bla g 1 and Bla g 2 in feces. J. Med. Entomol. 2010, 47, 1062–1070.
16. Fleurat-Lessard, F. Qualitative reasoning and integrated management of the quality of stored grain: A promising new approach. J. Stored Prod. Res. 2002, 38, 191–218.
17. Sinha, K.K.; Sinha, A.K. Impact of stored grain pests on seed deterioration and aflatoxin contamination in maize. J. Stored Prod. Res. 1992, 28, 211–219.
18. Beti, J.A.; Phillips, T.W.; Smalley, E.B. Effects of maize weevils (Coleoptera: Curculionidae) on production of aflatoxin B1 by Aspergillus flavus in stored corn. J. Econ. Entomol. 1995, 88, 1776–1782.

19. Morrison, W.R.; Bruce, A., Wilkins, R.V.; Albin, C.E.; Arthur, F.H. Sanitation improves stored product insect pest management. Insects 2019, 10, 77, doi:10.3390/insects10030077.
20. Zdarkova, E. Control of stored-food mites by non-chemical control. In Proceedings of the International Forum, Strasbourg, France, 7–8 November 1996; Council of Europe Publishers: Strasbourg, France, 1995; pp. 165–169.
21. Leesch, J.G. Carbon dioxide on the penetration and distribution of phosphine through wheat. J. Econ. Entomol. 1992, 85, 157–161.
22. Isikber, A.A.; Oztekin, S. Comparison of susceptibility of two stored-product insects, Ephestia kuehniella Zeller and Tribolium confusum du Val to gaseous ozone. J. Stored Prod. Res. 2009, 45, 159–164.
23. Tanguy, A.; Deudon, O.; Crepon, K. Average cooling availability for grain aeration in France over the last 20 years. In Proceedings of the Book of Abstracts of the 12th Conference of the Working Group Integrated Protection of Stored Products, Pisa, Italy, 3–6 September 2019; Conti, B., Trematerra, P., Eds.; p. 117.
24. Hamel, D. Higijena u skladištima poljoprivrednih proizvoda/Hygiene in storages of agricultural products. Glasilo biljne zaštite/Plant Prot. Bull. 2014, 4, 329–334.
25. Arthur, F.H. Structural pest management for stored product insects. In Recent Advances in Stored Product Protection; Athanassiou, C.G., Arthur, F.H., Eds.; Springer-Verlag GmbH, Berlin, Germany, 2018; pp. 65–81.
26. Jian, F.; Fields, P.G.; Hargreaves, K.; Jayas, D.S.; White, N.D. Chill-coma and minimum movement temperatures of stored-product beetles in stored wheat. J. Econ. Entomol. 2015, 108, 2471–2478.
27. Jian, F.; Jayas, D.S.; White, N.D.G. Movement and distribution of adult Cryptolestes ferrugineus (Coleoptera: Cucujidae) in stored wheat in response to temperature gradients, dockage, and moisture differences. J. Stored Prod. Res. 2005, 41, 401–422.
28. Hansen, J.; Johnson, J.; Winter, D. History and use of heat in pest control: A review. Int. J. Pest Manag. 2011, 57, 267–289.
29. Roesli, R.; Subramanyam, B.; Fairchild, F.J.; Behnke, K.C. Trap catches of stored-product insects before and after heat treatment in a pilot feed mill. J. Stored Prod. Res. 2003, 39, 521–540, doi:10.1016/S0022-474X(02)00058-9.
30. Porto, S.:M.C.; Valenti, F.; Bella, S.; Russo, A.; Cascone, G.; Arcidiacono, C. Improving the effectiveness of heat treatment for insect pest control in flour mills by thermal simulations. Biosyst. Eng. 2017, 164, 189–199, doi:10.1016/j.biosystemseng.2017.10.015.

31. Beckett, S.; Morton, R. The mortality of three species of Psocoptera, Liposcelis bostrychophila Badonnel, Liposcelis decolor Pearman and Liposcelis paeta Pearman, at moderately elevated temperatures. J. Stored Prod. Res. 2003, 39, 103–115.
32. Yu, C.; Subramanyam, B.; Flinn, P.W.; Gwirtz, J.A. Susceptibility of Lasioderma serricorne (Coleoptera: Anobiidae) life stages to elevated temperatures used during structural heat treatments. J. Econ. Entomol. 2011, 104, 317–324
33. Mahroof, R.; Zhu, K.Y.; Subramanyam, B. Changes in expression of heat shock proteins in Tribolium castaneum (Herbst) (Coleoptera: Tenebrionidae) in relation to developmental stage, exposure time, and temperature. Ann. Entomol. Soc. Am. 2005, 98, 100–107.
34. Communication From The Commission To The European Parliament, The European Council, The Council, The European Economic And Social Committee And The Committee Of The Regions The European Green Deal https://ec.europa.eu/commission/presscorner/detail/en/ip_19_6691 (accessed on 12 Jul 2020)
35. EU Biodiversity Strategy for 2030. Available online: https://ec.europa.eu/environment/nature/biodiversity/strategy/index_en.htm (accessed on 12 Jul 2020)
36. Communication from The Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions-A Farm to Fork Strategy for a fair, healthy and environmentally-friendly food system https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0381&from=EN (accessed on 12 Jul 2020)
37. Stejskal, V.; Vendl, T.; Li, Z.; Aulicky, R. Minimal thermal requirements for development and activity of stored product and food industry pests (Acari, Coleoptera, Lepidoptera, Psocoptera, Diptera and Blattodea): A review. Insects 2019, 10, 149, doi:10.3390/insects10050149.
38. Fields, P.; Subramanyam, B.; Hulasare, R. Available online: https://www.researchgate.net/publication/303249099_Extreme_temperatures (accessed on 13 July 2020).
39. Beckett, S.J. Insect and mite control by manipulating temperature and moisture before and during chemical-free storage. J. Stored Prod. Res. 2011, 47, 284–292.
40. Imura, O. Thermal requirements for development of stored-product insects. Tribolium Inf. Bull. 1990, 30, 58–68.
41. McKenzie, B.A.; Van Fossen, L. Managing Dry Grain in Storage Available online: https://www.extension.purdue.edu/extmedia/aed/aed-20.html (accessed on 23 October 2020).
42. Nayak, M.K.; Collins, P.J.; Holloway, J.C.; Emery, R.N.; Pavic, H.; Bartlet, J. Strong resistance to phosphine in the rusty grain beetle, Cryptolestes ferrugineus (Stephens) (Coleoptera:

Laemophloeidae): Its characterisation, a rapid assay for diagnosis and its distribution in Australia. Pest Manag. Sci. 2013, 69, 48–53.

43. Gorham, J.R. Ecology and Management of Food Industry Pests; Assoc. Off. Anal. Chemists: Arlington, VA, USA, 1991; p. 595.
44. Djekic, I.; Jankovic, D.; Rajkovic, A. Analysis of foreign bodies present in European food using data from Rapid Alert System for Food and Feed (RASFF). Food Control 2017, 79, 143–149.
45. Phillips, T.W.; Throne, J.E. Biorational approaches to managing stored-product insects. Annu. Rev. Entomol. 2010, 55, 375–397.
46. Hubert, J.; Stejskal, V.; Athanassiou, C.G.; Throne, J.E. Health hazards associated with arthropod infestation of stored products. Annu. Rev. Entomol. 2018, 63, 553–573.
47. Fernandez-Caldas, E. On mite allergy in dogs and humans. Int. Arch. Allergy Immunol. 2013, 160, 329–330.
48. Erban, T.; Stejskal, V.; Aulicky, R.; Krizkova-Kudlikova, I.; Nesvorna, M.; Hubert, J. The influence of environmental temperature and humidity on temporal decomposition of cockroach allergens Bla g 1 and Bla g 2 in feces. J. Med. Entomol. 2010, 47, 1062–1070.
49. Fleurat-Lessard, F. Qualitative reasoning and integrated management of the quality of stored grain: A promising new approach. J. Stored Prod. Res. 2002, 38, 191–218.
50. Sinha, K.K.; Sinha, A.K. Impact of stored grain pests on seed deterioration and aflatoxin contamination in maize. J. Stored Prod. Res. 1992, 28, 211–219.
51. Beti, J.A.; Phillips, T.W.; Smalley, E.B. Effects of maize weevils (Coleoptera: Curculionidae) on production of aflatoxin B1 by Aspergillus flavus in stored corn. J. Econ. Entomol. 1995, 88, 1776–1782.
52. Morrison, W.R.; Bruce, A., Wilkins, R.V.; Albin, C.E.; Arthur, F.H. Sanitation improves stored product insect pest management. Insects 2019, 10, 77, doi:10.3390/insects10030077.
53. Zdarkova, E. Control of stored-food mites by non-chemical control. In Proceedings of the International Forum, Strasbourg, France, 7–8 November 1996; Council of Europe Publishers: Strasbourg, France, 1995; pp. 165–169.
54. Leesch, J.G. Carbon dioxide on the penetration and distribution of phosphine through wheat. J. Econ. Entomol. 1992, 85, 157–161.
55. Isikber, A.A.; Oztekin, S. Comparison of susceptibility of two stored-product insects, Ephestia kuehniella Zeller and Tribolium confusum du Val to gaseous ozone. J. Stored Prod. Res. 2009, 45, 159–164.

56. Tanguy, A.; Deudon, O.; Crepon, K. Average cooling availability for grain aeration in France over the last 20 years. In Proceedings of the Book of Abstracts of the 12th Conference of the Working Group Integrated Protection of Stored Products, Pisa, Italy, 3–6 September 2019; Conti, B., Trematerra, P., Eds.; p. 117.
57. Hamel, D. Higijena u skladištima poljoprivrednih proizvoda/Hygiene in storages of agricultural products. Glasilo biljne zaštite/Plant Prot. Bull. 2014, 4, 329–334.
58. Arthur, F.H. Structural pest management for stored product insects. In Recent Advances in Stored Product Protection; Athanassiou, C.G., Arthur, F.H., Eds.; Springer-Verlag GmbH, Berlin, Germany, 2018; pp. 65–81.
59. Jian, F.; Fields, P.G.; Hargreaves, K.; Jayas, D.S.; White, N.D. Chill-coma and minimum movement temperatures of stored-product beetles in stored wheat. J. Econ. Entomol. 2015, 108, 2471–2478.
60. Jian, F.; Jayas, D.S.; White, N.D.G. Movement and distribution of adult Cryptolestes ferrugineus (Coleoptera: Cucujidae) in stored wheat in response to temperature gradients, dockage, and moisture differences. J. Stored Prod. Res. 2005, 41, 401–422.
61. Hansen, J.; Johnson, J.; Winter, D. History and use of heat in pest control: A review. Int. J. Pest Manag. 2011, 57, 267–289.
62. Roesli, R.; Subramanyam, B.; Fairchild, F.J.; Behnke, K.C. Trap catches of stored-product insects before and after heat treatment in a pilot feed mill. J. Stored Prod. Res. 2003, 39, 521–540, doi:10.1016/S0022-474X(02)00058-9.
63. Porto, S.:M.C.; Valenti, F.; Bella, S.; Russo, A.; Cascone, G.; Arcidiacono, C. Improving the effectiveness of heat treatment for insect pest control in flour mills by thermal simulations. Biosyst. Eng. 2017, 164, 189–199, doi:10.1016/j.biosystemseng.2017.10.015.
64. Beckett, S.; Morton, R. The mortality of three species of Psocoptera, Liposcelis bostrychophila Badonnel, Liposcelis decolor Pearman and Liposcelis paeta Pearman, at moderately elevated temperatures. J. Stored Prod. Res. 2003, 39, 103–115.
65. Mahroof, R.; Zhu, K.Y.; Subramanyam, B. Changes in expression of heat shock proteins in Tribolium castaneum (Herbst) (Coleoptera: Tenebrionidae) in relation to developmental stage, exposure time, and temperature. Ann. Entomol. Soc. Am. 2005, 98, 100–107.
66. Yu, C.; Subramanyam, B.; Flinn, P.W.; Gwirtz, J.A. Susceptibility of Lasioderma serricorne (Coleoptera: Anobiidae) life stages to elevated temperatures used during structural heat treatments. J. Econ. Entomol. 2011, 104, 317–324