Daglish, G. J., and Pavic, H. (2008). Effect of phosphine dose on sorption in wheat. *Pest Management Science, 64*(5), 513-518.

Darby, J. (2011). *Technology to overcome inadequate fumigations and resistance selection.* (No. CRC50059). Black Mountain, ACT, Australia: Cooperative Research Centre for National Plant Biosecurity.

Dumas, T. (1980). Phosphine sorption and desorption by stored wheat and corn. *Journal of Agricultural and Food Chemistry, 28*(2), 337–339.

Cook, S. (2016). Evaluation of sealed storage silos for grain fumigation. (Unpublished Master of Science thesis). Kansas State University.

Isa, M. Z., Fulford, G. R., and Kelson, N. A. (2011). Simulation of phosphine in vertical grain storage: A preliminary numerical study. *Australian Mathematical Society*, (52), 759-772.

Isa, Z. M., Farrel, T. W., Fullford, G. R., and Kelson, N. A. (2016). Mathematical modelling and numerical simulation of phosphine flow during grain fumigation in leaky cylindrical silos. *Journal of Stored Products Research, 67*, 28-40.

Lawrence, J. (2010). *Three dimensional transient heat, mass, momentum and species transfer stored grain ecosystem model using the finite element method* (Unpublished Ph.D. dissertation) Purdue University, West Lafayette, Indiana.

Lawrence, J. and Maier, D. E. (2011). Development and validation of a model to predict air temperatures and humidities in the headspace of partially filled stored grain silos. *Transactions of the American Society of Agricultural and Biological Engineers, 54*(5), 1809-1817.

Price, L. A., and Mills, K. A. (1988). The toxicity of phosphine to the immature stages of resistant and susceptible strains of some common stored product beetles, and implications for their control. *Journal of Stored Products Research, 24*(1), 51-59.

Plumier, B. M., Schramm, M., and Maier, D. E. (2018). Developing and verifying a fumigant loss model for bulk stored grain to predict phosphine concentrations by taking into account fumigant leakage and sorption. *Journal of Stored Products Research*, 77, 197-204.

Reed, C. C., and Pan, H. (2000). Loss of phosphine from unsealed bins of wheat at six combinations of grain temperature and moisture content. *Journal of Stored Products Research, 36*(3), 263-279.

Sato, K., and Suwanai, M. (1974). Adsorption of hydrogen phosphide to cereal products. *Japanese Society of Applied Entomology and Zoology, 9*(4), 127-132.

Sun, Y.P. (1946). An analysis of some important factors affecting the results of fumigation on insects. St. Paul, Minnesota Agricultural Experiment Station. Technical Bulletin No. 177.

A Novel Engineering Design of Small Scale Metallic Silo for Food Safety in Rural India

Arjoo Nandal*, Santosh Satya, K. K. Pant, S. N. Naik

Centre for Rural Development and Technology, Indian Institute of Technology, New Delhi 110016, India.
*Corresponding author: arzoo.nandal.89@gmail.com
DOI 10.5073/jka.2018.463.082

Abstract

Wheat is an essential component of the human diet for most of the world. In India wheat is an important staple food crop and it is used for the preparation of a diversity of products like *roti*, *parantha* (semi fried), *puri* (fried), bread, pasta, noodles, buiscuits etc. It has been reported that ~60-70% of wheat produced is stored at home or farm levels for domestic consumption. In order to understand the rural grain storage system, an extensive field study was carried out in villages of Haryana state (India). The field study revealed that ~95% of families store their grains in metallic silos of different sizes (300 to 2000 kg) and only Aluminium phosphide tablets (locally called sulfas) are used to protect grains from storage pests. Aluminium phosphide (AlP) tablets are used in an unscientific manner to control insect pest infestation, resulting in residues in stored grain. An experimental study of 12 months was carried out to identify the problems associated with pest management in conventional metallic silos. The storage period was divided into two parts, i.e., summer and winter, of 180 days each. Ambient temperature and relative humidity (RH) were recorded continuously for the entire period and temperature inside the silos was also recorded at different locations. The emergence of 'hot spots' was found during May-June when the temperature ranged from 37.6 to 42.7°C inside the silo during the summer season. During this period ambient temperature and RH ranged from 22.6-44.2°C and 37-82%. At this stage, convection current caused moisture migration at the top and bottom of the silo, whereas in the winter season moisture migration inside the silo was observed only at the top layer. Wheat samples from the topmost layer, in the vicinity of the "hot-spot" and from the bottom layers were collected and analyzed for various quality parameters.

The wheat samples near the "hot-spot" emergence were found most deteriorated in every aspect, for instance, in terms of protein content (decreased by 21.77%), fat content (decreased by 64.05%), germination capacity (decreased by 84.06%), thousand kernel weight (decreased by 22.09%), ash content (decreased by 41.96%), acidity (increased from 3.07-6.23 mm/gm) and insect-damaged kernels (increased by 80%). The results confirmed that even in a very small silo of 100 kg capacity if grains are stored without any fumigation treatment,

there exists the potential for moisture migration because of temperature fluctuation causing hot-spot formation, leading to grain quality deterioration.

Keeping in view the above aspects, an integrated engineering design of a double wall metallic silo with the special provision of a vertical perforated metallic tube in the centre was designed and fabricated. Tri-layer materials were tested for their thermal properties for fulfilling the needs of thermal insulation in the double wall silo. Wheat straw was found to be the best material in terms of thermal conductivity with a value of 0.040 W/mK. The special provision consisted of a removable string fitted with plates for keeping AlP tablets. To understand the function of the perforated tube in the centre of the silo for preserving stored wheat quality, 100 Kg of wheat (HD2733) was filled in this silo and after 12 months storage, wheat samples (at different depths inside the silo) were collected with the help of grain probes and mixed properly for quality parameter determination. Seed germination was determined before and after storage. It was found that germination decreased from 96% to 84%. Moisture content increased during storage from 9.8 to 12.7%. The initial kernel damage observed was 2-3% whereas after storage it was in the range of 13-15%. The initial lipid content recorded was 2.08% whereas after storage it was 1.4%. Also, the protein content decreased by 9.01%. Other parameters also showed quality degradation with time. The results were compared with the control (conventional) silo and it was found that the newly designed silo was better in terms of preventing insect infestation and quality deterioration. Also, the newly designed silo had a special provision for keeping AlP tablets suspended in the perforated tube to better control insects.

Future vision

The gap in technology transfer in India is increasing the chemical load on stored grain which can be minimized by incorporating small changes in the existing design of silos. To avoid the unnecessary repetitive use of AlP tablets, scientific knowledge should be developed and adopted, for example, on suitable wrapping/packaging material for AlP release at a slow rate over longer periods for effective control of insect pests in stored grains.

Keywords: Wheat, thermal conductivity, AlP, insect trap, design.

Food industry practices affecting Integrated Pest Management

Pasquale Trematerra[1*], Francis Fleurat-Lessard[2]

[1]Department Agricultural, Environmental and Food Sciences, University of Molise, Campobasso, Italy
[2]INRA Bordeaux-Aquitaine, Villenave d'Ornon Cedex, France
*Corresponding author: trema@unimol.it
DOI 10.5073/jka.2018.463.083

Abstract

Manufacturers of dry food products have a real challenge to exclude pests everywhere along the food chain because of the rather complex and different environments of food industry buildings. Current practices that influence pest presence and development in food industry facilities have been identified in the stages of food plant design, food ingredient reception and storage, processing or conditioning of finished food, and marketing. The preventive pest control measures in the food industry may be ineffective because of a non-observance of simple rules of good manufacturing practice (GMP), such as permanent control and monitoring of critical points or the ban of unsafe practices favourable to pest entry and infestation in food plants. The underutilization of methods for rapid assessment of pest presence and movement within food industry facilities, as well as the inability to rely on pest monitoring data for the economic damage threshold (EDT), are also underlined. Practical tools for processing data from pest monitoring systems should improve pest presence detection and alert. More realistic EDTs need to be proposed with direct links to decision-making support. More practical predictive models are also required for predicting the long-term efficacy and resilience of corrective control methods in food processing buildings, which should render the implementation of complex IPM programs easier.

Keywords: pests, food industry, manufacturing practices, food processing, IPM program

1. Introduction

Pest management practices in food industries are facing an important need to protect durable food products against pest infestation as many markets have very low pest-induced damage tolerance and are also subject to increasingly intense scrutiny through external inspections and audits. There are somewhat antagonistic trends such as less reliance on the use of residual pesticide treatments and the demand for perfect food products, free of pesticide residues, which is becoming today one of the main challenges faced by the food industry in the field of pest management. However, food facilities typically are large complex structures with many locations vulnerable to insect pest infestation. They differ from each other in their activity or function (warehouse, mill, food processing plant, retail store, supermarket), in the concerned commodity (cereals, legums, animal-based materials, spices, dried fruits, cocoa), in the type of product generated (whole grain, flour, human food, pet food, confectionery, feed, etc.), in structure type (old or new, with variable construction material), in their equipment, in their geographic location and surrounding landscape, etc. This makes generalization about the pest infestation risks extremely complex and difficult: pest situation of a particular food industry facility has very specific characteristics for a given location.

Pest management in food facilities is a prerequisite for achieving food safety and food hygiene considering the scope of global quality assurance systems (HACCP). Recent regulations (EU Hygiene package and US Food Safety Modernization Act of FDA) aim at enforcing the application of HACCP systems to all food chains and in all plants, distribution centers and grocer's or retail stores. The main objectives of this paper consist in the analysis of the practices in the food industry affecting the risk level for both pest infestation risk and decision-making process for IPM related to food hygiene HACCP system conception and implementation, specifically adapted to the dry food industry sector.

2. Pest exclusion measures and sanitation in food industry facilities

Most buildings provide three main attractions for pests: shelter, food and warmth. It is commonly assumed that older buildings are more prone to infestation, but new buildings with enclosed roof spaces, suspended ceilings, wall cavities, panelling, raised floors, service ducts and lift shafts provide a large number of harbourages – with many interconnections – allowing a wide range of internal movement for pests. Most pests actually require very small amounts of food – an adult mouse for example, can survive on as little as 3 grams a day. A few degrees increase in temperature may be sufficient to encourage infestation, particularly in winter months. A master sanitation schedule is a vital component that influences pest management in the food industries. Importance of sanitation programs, and constant requirement for training personnel to implement sanitation practices are essential.

Elimination of pest refuges and pest colony "nests"

Harbourage of insect colonies

Constant monitoring of insects with different techniques and particular attention on behalf of staff prevent heavy infestations. This was accomplished by limiting Lepidoptera and Coleoptera populations by intensive trapping with pheromone and food traps, by examining tracks on dust left on floors or machine supports, substituting wooden structures with metallic ones, sealing cracks and crevices in walls and floors and replacing screw conveyors with pneumatic (fluid-lift) conveyors. Some elements in building structures and machinery needed to be changed or replaced (*e.g.,* gaskets). Crevices in which debris could accumulate must be sealed, wall edges and column floor junctions shoud be modified to avoid food particles accumulation.

Cleaning and hygiene maintenance

The removal of debris is more efficient than any localized chemical treatment. Only by controlling the entire processing cycle, from the purchase of raw material to the distribution of the finished product, will it be possible to reduce the risk of infestation. Nowadays, a few quality managers of food industries consider the problem of maintaining proper hygienic conditions as really important, although it represents the first step in reducing pest infestations. However, in many cases, standard cleaning procedures were modified but staff was not trained to clean the least accessible areas that are generally neglected. Therefore these are sure to be sources of infestation, and thus being considered as a potential critical control point. The most vulnerable points may be identified by visual inspection of trained personnel, or better by an external audit carried out by a sanitation specialist. The attention of all staff should be drawn to the importance of cleanliness as it is their duty to adhere to these recommendations.

Influence of physical condition control

Site location and structure type design

Knowing that some pest infestation risks can originate from the proximate environment of any food plant, the perimeter around all structures and between structures should be kept free of vegetation and better with a concrete pavement of minimum one meter wide. The basement walls of food plant buildings should be “insect proof” at the junction with the steel cladding of the building wall. The repair of these damages creates critical entry points for pests that need to be quickly achieved and visual inspection of the exterior of the buildings should be easy all around. Where a new construction is being considered, an assessment of activities and the environment in the proximity to the proposed site must be made. Landfill sites, watercourses, marshlands, derelict sites, farms are examples of activities that regularly generate pest activity. When an old industrial building is re-used, the previous use of the site and its pest history must be considered. Thus, buildings that have previously been used in the food industry are most likely to have a pest history. Retrospective repair is far harder to accomplish once production has started and is running and when the construction company no longer has a presence on site. As a formal rule, no food should be allowed on to the site being constructed.

Temperature and air-conditoned manufacturing units

The population dynamics of stored product insect pest such as *Plodia interpunctella* or *Tribolium* spp. - which are common species in food industry facilities - is at their optimum in the range of 25-30°C. In factories producing cooked products (such as biscuits or bread), ambient temperature may be in this range all the year, especially in the rooms where cooking ovens produce heat. These areas have an increase risk of insect pest presence such as *P. interpunctella* which may lay eggs on the product after cooking. As an example of risky situations, when a belt covered with cooling biscuits stops (because of a technical issue), cooled biscuits are available to *P. interpunctella* female for egg deposition. One solution to this issue is to cool the food production areas with unprotected food flow to below the lower threshold of moving activity of flying insects (*P. interpunctella* or *Ephestia* spp. or *Stegobium paniceum*), *i.e.,* below 15°C. Below this lower limit, insects remain quiet and do not lay eggs on the produce before wrapping (*e.g.,* biscuits) and packaging. Consequently, air conditioning production areas to temperatures of 14-15°C or lower is a recommended practice that inhibits insect movements.

Internal and external lighting of the buildings

The type of lighting at a premise will, to a certain extent, determine the attractiveness of the site to flying insects. Most attractive types are mercury-vapour lamps and special fluorescent lamps used for perfect colour rendition. Next come “ordinary” commercial and household fluorescent tubes. The warmth of infrared light is also attractive to insects, although the area of attraction surrounding the source will probably extend only for a few meters. High-pressure sodium-vapour lamps, however, emit very little UV or IR and are currently thought to be the least attractive to insects. Unfortunately, these lamps give an orange light and cannot be used where the recognition of colours is important. It is recommended that an absolute minimum amount of lighting is physically attached to the building. Instead, position lights 5 or 6 meters away and direct lighting towards doorways. Apart from the obvious benefits of attracting insects away from the building, there are also benefits to be obtained in making the building less attractive to geckos, bats and birds that often roost and nest on such lighting structures due to their warmth. Lighting just inside doorways and in loading bays should be high-pressure sodium-vapour or low wattage incandescent bulbs.

White or light yellow surfaces of buildings should be avoided due to their ability to reflect UV light. Darker blue or green colours are preferable.

Exterior environment of food industry buildings

Perimeter security fences are generally of chain-link, wire mesh, weld-mesh or metal railing construction. These should be set into concrete footings to prevent mammals gaining entry under the fence. In the immediate building perimeter, concrete pathways are preferable to gravel pathways as gravel could be burrowed into by rodents despite of the ability of gravel to back fill on itself. Paving slabs are often laid on sand, which is conducive to infestation by ants and allows mole gallery digging.

Water drainage

Pooling water from overflow will encourage various pests, particularly flies. A readily available source of water is also a requirement for successful rat populations. Good drainage of land is required to avoid waterlogged soil. Certain insect pests (*e.g.,* cockroaches) rely on a water source for breeding. Grids should be designed so that waste materials can pass through easily and they can be removed easily for cleaning.

Increased risk of infestation by exterior environment

It is not advisable to plant trees or bushes near a food facility that will result in direct contact of tree leaves and branches with the exterior wall of the facility. This should be systematically avoided, because foliage provides excellent harbourage for many pest species. At a respectable distance from the walls, preference should be given to plants that shed the least seeds and fruits. Seeds and fruit may initially attract and then support insects, rats and mice, and various pest birds. Shrubs and trees should be of a coniferous type (releasing flavor repulsive for a range of food industry related insects). Leaf fall from deciduous trees that accumulates in guttering will restrict the run-off of rainwater and may give rise to localised infestations of insects that rely on standing water to breed, for example midges and mosquitoes. Leaves that accumulate along foundations provide harbourage and sheltered runs for rats and mice. Tree limbs and branches should be at least 2 m away from building exteriors (3 m if squirrels are a problem). Plants should not be planted too densely. Dense ground cover will provide cover and harbourage for rodent pests. Access in between shrubs is important for pest control inspection. Vegetation should not encroach within 5 m from any outside wall of a building. Rural vegetation can aggravate both rodent and insect pests. Climbing plants should not be planted against the walls of buildings. These could create entry routes for pest rodents, harbourage for pest bird species and entry routes for some insect pests. Grass should be kept closely cut at all times. Long grass will offer cover and harbourage for rodent pests. Raining water downspouts are easy ways for rodents to climb near the roof of the buildings to reach access to the space between the roof and the wall existing in numerous buildings.

Risks related to building structure design

Wall foundations must be taken down to a solid bottom at least 80 cm below ground level and concrete laid between the walls to prevent rodents burrowing into the building. The addition of a concrete curtain wall to a depth of 60 cm will protect the foundations against rodent ingress. It may be appropriate to apply a band of “non-friction” material 1 meter above ground level to prevent rodents climbing external walls. Airbricks supply ventilation to walled cavities but they also may allow mice and insect pests access. Pre-formed corrugated cladding should be avoided as corrugations are difficult to seal adequately against pest entry at the point where they meet conventional walling. An epoxy-resin type material should be considered. The external surface of walling should have no ledges because ledges may provide suitable day or nighttime roosts for pest bird species. For the same reason, over-developed external wall fascia should be avoided. The internal surface of walling should have no ledges. Ledges provide suitable areas for product residues to accumulate and are difficult to access for cleaning. All drains should be accessible (from visit 'openings') and facilitate flushing and rodding. Special attention must be given to vertical ducts that pass between floors. Ducting may also allow rodent and insect pests free movement between floors (Troller, 1993).

Interior design of food plants and stores for pest-proofing

Floor, walls and ceilings design and colour

Tiled flooring is not recommended. All expansion joints should be well sealed and sealing material should be made from a material that allows for movement. Flooring under equipment (sur-elevated from the floor) should be completely smooth to allow thorough removal of waste material. Covings at wall to floor junctions reduce the accumulation of debris and facilitate effective cleaning. All cracks and crevices should be sealed to prevent the accumulation of product residues that provide insect breeding sites. Buildings are often designed in a way hard to reach for regular cleaning, for example roofs or very high ceilings, accumulate dust and debris and serve as a harborage for pests. So, one of the key industry practices that affect pest management is the building design.

Available access of pests to food and/or water inside food facilities

As rodents, birds and cockroaches rely on a supply of drinking water, sources of free water should be avoided. Any pools on concrete floors or on flat roofs have to be removed. Drainage channels should be sufficiently wide to accommodate expected volumes. They should be fitted with drainage grills that do not clog with waste and are easily removed for cleaning. The ends of drainage channels should be buttressed so that waste does not accumulate. Rainwater down pipes should be fitted externally; rodent entry into a down pipe from the ground can be prevented by the use of a back inlet gully. Pipes and cables, *i.e.,* gas, electric and water, must be tightly sealed where they pass through walls as rodents may gain entry via this route. Ducts can be sub-divided to prevent rodents gaining access along their length.

Doors, windows and portal apertures

Exit doors should be a good fit and self-closing; with a sensor to detect if the door has been properly open. Rats and mice can move around within a building via gaps that exist below doors. Roll-up doors should be fitted with a flexible bottom "seal" and T extensions to fit rail tracks. The use of strip curtain doors or rubber flap-back doors around external wall door openings should be avoided. Automatic high-speed roller doors are preferable but their timing needs to be adjusted so that they are open for the minimum amount of time. Vehicle loading ports should be adequately sealed once trailers have docked, and the port doors should not be opened until trailers are completely in position. Open loading ports equipped with lights will attract night flying and daytime flying insects. Installing doors that have hollow frames is not a recommended practice. Mice may use hollow doorframes as harbourage. Insects can breed in the accumulated food debris inside the base of the frame. Although opening windows can be adequately screened against flying insect ingress, air conditioning with light positive pressure inside the building is preferable. Nevertheless, a useful device to protect buildings from flying insect entry is the air curtain. Especially points of lorry loading openings, where doors are not very tightly closed, can be effectively protected from flying insects by this device. Outside air containing flying insects can be drawn into buildings that have negative pressures. Pest birds may use window ledges as day or nighttime roosts. Ceiling voids are potential harbourages for pests. Enclosed voids can also make inspection for pests difficult. GMP compliances for point of entries and common sense practices can eliminate pest infestation.

Storage of food products above ground level

Racking should be used to keep all goods off the floor. Raising goods will also allow effective cleaning. Adequate space around racking should be allowed. This will facilitate good pest control inspection and allow for thorough cleaning. The pillars supporting the rack for pallets of raw food commodities are often protected from shocks by metallic shields that may house dust and food ingredients. These pods of pallet racks must be regularly cleaned to avoid insect colonies to establish in such protected locations. Adequate space between racking bays should be provided. This will allow for good pest control inspection and allow for thorough cleaning. Good stock rotation methods should be enforced. A minimum quantity of ingredients/packaging should be kept in stock; it is preferrable to have suppliers who are flexible enough to supply on demand. The use of pallets constructed of wood should progressively be replaced by the use of plastic pallets. Storage shelving should not have concealed cavities. If spillages cannot be cleaned easily, pests may make use of them to conceal their harbourages. Cleaning floors and wall basis must be regularly carried out and if possible each day.

Organization of food product chain

Food processing chain organization

The major principle of product flow organization in a food processing plant is that raw material and processed or finished produts should not be in close proximity. The strict separation of raw and processed product is essential to avoid contamination of any kind. The GMP recommendation for product flow direction in the process area is in compliance with the “go forward” principle, without raw ingredients that never cross processed or semi-processed food line. Because insect pest development cycles last a minimum of one month in indoor conditions, raw food commodities must be kept a minimum period of time in storage workshops. So, in all storage rooms, the product flow must comply with the “first in, first out” principle so that the stock rotation should be as short as possible. On the line for dry food product processing, there is a critical need to ensure a sanitary environment.

Cleaning material and equipment

The cleaning should focus on ingredients and dough fragments that have fallen down and have accumulated below the conveying belts or are sticking on belt support rollers. All residues in machinery should be removed at a regular interval (*e.g.,* each day) and the whole machinery should be thouroughly cleaned after each change in product type or before long shut-down periods. The food products waiting on a stopped conveyor for more than half an hour should be immediately removed and should not be stored in open containers close to the processing chain. Equipment which is to be taken out of production for a long period of time must be thoroughly cleaned to remove all food residues. All these cleaning practices are part of GMP and comply with the principles of proper sanitation in the food system sustained by recent regulations such as the Food Safety Modernization Act, enacted in 2011, or the EU Food Hygiene regulation package (Anonymous, 2004).

Underused packaging and food materials

Little used ingredients and packaging material are more likely to have pest activity develop in them and to be used by pests as harbourage. As an example, corrugated cardboard material temporarily stored in a food processing area may be a perfect refuge for migrant larvae of the Indian meal moth.

Isolation and treatment of infested commodities and out-of-use material

The construction of a quarantine building is recommended for the isolation of infested commodities or commodities that are being received from a suspect supplier. Returned goods should be stored in their own quarantine area away from ingredients, packaging and finished goods - ideally in a separate building unconnected to main production and warehousing areas. When food processing or packaging material is out of use, this equipment always remains attractive from food product or food dust deposit inside, which may attract flying pests. This “out-of-use” equipment should be rapidly disposed off from workshops containing raw ingredients or processed food.

Packaging defaults (imperfect insect proofing)

Finished food produced from food processing plants is susceptible to quick infestation all along the marketing channels if packaging material is permeable to food flavor. This permeability to food flavor is a common weakness of a lot of cheap packaging films that are used to package finished food products. The result of such permeability generally is a rapid localisation of appropriate feed substrate by flying insects (*e.g., Plodia interpunctella*) or by rodents. Additionally, certain types of package (cardboard cassette and boxes with flexible pouring spout, or bags with wide aperture without resealing system after first use) are no more preventing insect entry after first aperture and the first pick up of food.

3. Early detection of pest presence and monitoring insect pest density

Identification of vulnerable situations for pest in food industry

Visual inspection “corridor” between products, machinery and walls

In storerooms, stacking of goods should be about 30 – 50 cm away from walls to allow free access to the area behind for inspection and cleaning. Strict segregation is required between raw materials, food processing areas, finished food products, and packaging zone to prevent cross-contamination. Plant and other equipment must be free of infestation before being brought on site. Rubbish storage areas must be kept tidy, using only close-fitting containers regularly emptied.

Management of waste

Waste areas should be sited more than 10 m away from the main building in order that any pests that may be attracted are kept at a distance. All waste bins should have tight fitting lids which must be kept closed at all times. If individual bins or skips are not covered, then the area should be enclosed within a mesh cage to prevent access by birds. Waste skips should be placed on a concrete pad to prevent rats burrowing underneath and be situated on rails of a height that will allow for thorough cleaning below.

Factors limiting IPM strategies implementation in the food industry

Full implementation of the IPM approach requires more effort than other types of control programmes, but once in place, it can be used to make more reliable pest management decisions. Unfortunately, many of the studies reported in the literature have been achieved under laboratory conditions, so there is limited information on their integration under field conditions. The IPM strategy is based on corrective intervention in dependence on EDT.

Self-determination of EDT and decision support tools use

Relationship between monitoring data and pest infestation level prediction

Many of the components of an IPM programme are known and are available for use, but our understanding of how to optimally integrate and target these tactics as part of IPM is limited. An IPM program is an evolving process that applies local intelligence and responds to changing needs (Pinniger and Child, 2002). Adoption has also been hindered by: i/ a poor understanding of pest population displacement in the spatially and temporally complex landscapes where food is processed and stored; ii/ the difficulty of evaluating pest populations; iii/ the limited information on structure treatment efficacy, and iv/ how to optimally select and combine management tools. Many questions remain about the use of these tools: from the very practical issues such as how many traps are needed and which types work best, to fundamental issues concerning the relationship between trap captures and pest population density, distribution and level of infestation.

- **Strengthening pest monitoring programs for food industry**

Insect monitoring is a primordial component of pest management in food processing plants (Campbell et al., 2002). Economic losses due to insects and unnecessary pest management expenses can be avoided using insect monitoring and decision-making tools related to risk prediction by the assessment of EDT, predictive models of pest populations density changes over time, and expert systems to determine the best time and way to suppress pest populations (Arthur and Phillips, 2003; Fleurat-Lessard, 2011). Computer simulation models can be used to compare the effectiveness of different pest management methods, alone or in combination, for stored-product insects. These models can also be used to evaluate the effectiveness of different implementation options, and to optimise the timing of pest management programs for stored-product insects (Fleurat-Lessard, 2011; Campbell et al., 2012). Currently, computer simulation models are available primarily for insect pests of stored grain, but in the future such models should be particularly useful in decison-making for pest management strategies for dry food processing and marketing chains (Trematera, 2013).

4. Modern tools to be integrated in IPM programs for pest risk minimization

As stated by Adam et al. (2006) in the case of implementation of IPM in stored-grain, many quality managers of food plants have not yet adopted IPM practices for many reasons: additional cost or personel implication, minimum required knowledge, difficulty to adopt a new technology by the managers, pressure of pesticide supplier or fumigation company, etc. Limited acceptance of IPM in food facilities is partially explained by a combination of the costs of corrective pest control interventions, difficulties in sampling properly, unreliable data, and difficulties encountered in the calculation of meaningful EDT. Precise treatment thresholds and economic injury levels have not been completely established for operational practice, and standards and rejection criteria are inconsistent and difficult to apply. As a result, treatments based on an economic threshold are not typically performed and control strategies are often applied preventatively, even when using tactics that do not have any residual effect. In current practice, many locations still rely on calendar-based pesticide applications and have little understanding of the basis of pest management. Nevertheless, most of the risks of infestation of food industry plants by noxious pests listed above may be controlled by customized application of IPM programs covering the four components of dry Food Quality and Safety Assurance from raw commodities to finished food products (Tab. 1). Combining and integrating different management tools and careful selection and timing of different approaches, together with an understanding of pest behaviour and ecology, should result in a greater effectiveness and more accurate solutions to pest presence in finished food.

Peculiarities of bulk-stored commodities

For bulk-stored commodities, and particularly in commercial elevators, it is often difficult to adequately monitor large grain bulks due to the need to directly sample the large volume of grain and detect relatively low densities of insects. Collecting samples may only give information on insect presence when relatively high densities are present. The lower limit of density that can be expected from bulk sample examination is evaluated at one insect per 2 kg of raw material (as grain) (Fleurat-Lessard, 2011). This is already a high level of infestation and much higher than most of the tolerable EDT (more often fixed at one insect per 5 kg of grain). As grain products move from bulk storage to processing and milling facilities, then through distribution and marketing channels to consumers, the concept of EDT becomes more difficult to apply. When there is 'zero tolerance' for insects, controls become more preventative, but it is not very realistic. More often with bulk raw commodities, there are no precise damage thresholds or injury levels, and it may be difficult to adequately determine pest levels or to estimate all of the direct and indirect costs of corrective interventions. In this context, there is reluctance or lack of interest on the part of the food grain storage and handling industry to move away from calendar-based pesticide treatments to a more integrated approach, based on prevention rather than control after EDT is reached. This is due, in large part, to a justifiable concern about making mistakes with pest control in an industry with an extremely low pest threshold requirement.

Difficulty of applying biocontrol agents in the food industry buildings

The artificial nature of food chain environments and low tolerance in many situations for the presence of insects, means IPM relies less on promoting population regulation using natural enemies and puts greater focus on modifying the environment to make it less favourable for pest establishment and persistence. The exception to this is bulk storage, where biological control shows more potential for success since some insects can be tolerated in many situations and natural enemies can be cleaned out of the material before processing (Schöller and Flinn, 2000; Phillips and Throne, 2010).

A summary of the more promising modern tools that may be integrated to IPM programs for the food industry is described in Tab. 1. The IPM concept is a whole system based on risk prevention, monitoring and prevision including pest resistance management, use of selective chemical treatments, use of corrective intervention thresholds, and promoting environmental sustainability.

5. Further research needs for larger implementation of IPM in the food industry

Research should optimise or further develop other semiochemicals (attractants and repellents) to aid in the monitoring of some stored-product insects and to provide new biocontrol tools. In this regard, future stored-product protection combinations of repellents and attractants may also find use in push-pull tactics (Cook et al., 2007). Push-pull strategies involve the behavioural manipulation of insect pests and their natural enemies via the integration of stimuli that act to make the protected resource unattractive or unsuitable to the pest (push) whilst luring them towards an attractive source (pull) from where the pests are subsequently removed. Deterrent or repellent semiochemicals can be used to discourage pests from entering a premise, while at the same time, attractants or stimulants can encourage pests to congregate in an adjacent area where they can be controlled more effectively and safely by chemical pesticides or biocontrol agents. Computer, smartphone and touchpad applications affording a practical and user-friendly support in building IPM specific programs and on-line advice for risk assessment and prevention should become accessible to food industry quality managers in the near future.

Tab. 1 IPM more recent tools that may be integrated in IPM programs for the food industry.

IPM component	Actions for risk management	Alternative tool	Main advantage	Main constraint
Identification of critical pest entry points in food industry facilities	Identification of critical points by which insect pests can penetrate into the facility	Interpretation of trap network data with geographical positioning system (GPS)	Accurate detection of the core of infestation	Each trap bar-coding and GPS positioning of each trap
		Localisation of loci of pest infestation by contour mapping from trap catches	Accurate localisation of infested goods	Weekly trap data processing
Pest exclusion measures for risk prevention	Sanitation measures especially at pest entry points and regular inspection and surveillance of identified CCP. Regulation of physical conditions	Low temperature and RH in working areas when free-access food is on the chain	Corrective treatment never needed	Air conditioning of all rooms
		Pest-proof packaging film and structure for finished food products for sale	Protection from pests in the marketing channels	Bioassay to carry out for food bag or box testing insect proof properties
Permanent monitoring for risk prediction	Identification of infestation locations inside the building, processing equipment and machinery	Enhanced strategies of pheromone use: mass-trapping and attract-and-kill strategies	Effective means of surveillance for flying insects	Not adapted to limit crawling beetles populations
		Permeation of food facility atmosphere with pheromone for mating-disruption or auto-confusion	Effective against flying insects	Slow reduction of pest population expensive renewal of dispensers
		Use of electronic devices detecting very low level of insect density in bulked commodities	Early detection especially for grain insect pests	Only useful for insect detection in bulked commodities
		Prevision of pest density changes over time by predictive models from physical-chemical parameters or conditions	Calculation of safe storage time before EDT reaching	Collection of daily data of temperature and RH for model feeding
Application of pest control measures (when EDT is reached)	Selection of non-chemical solutions rather than chemical disinfestation means develop the use of biocontrol or beneficial agents	Pheromone trap use for auto-inoculation-release of a microbial pesticide	Self-function device	Expensive and slow in action
		Improvement of efficacy of registered pesticides by combination with mineral products or biorationals	Lower risk of chemical residues in food	Preventive action; weak curative effect
		Replacement of surface or space treatments with chemicals by bio-control agents or biopesticides	Targeting more specific pest species than chemical pesticides	Difficulties to register for use in food processing plants
		Use of physical treatment as alternative to fumigation (microwave heating, temporary freezing, controlled- and modified-atmospheres)	Complete disinfestation process with neither persitence nor residual effect	Competitive only for high value commodities (e.g., medicinal plants and spices)
		New fumigants for whole structure, plant or warehouse disinfestation (SO_2F_2, methyl iodide, ethyl formate …)	Complete disinfestation of food plants or stores in a sigle fumigation	Minimal airtightness of buildings required; manager reluctance
		Use of natural pesticides of microbial or fungal origin, a vegetal extract or an essential oil (EO)	Short period of remanence (activity and smell) for the most volatile EO	Difficulty to register fomulations from a few number of active substances
		New formulation or conditioning of phosphine controlled-release phosphine gas by automatic equipment	More practical implementation and control of fumigant doses	Managers reluctance to regularly use toxic gas at a high concentration
		Replacement of fumigation of food-processing plants by heat disinfestation	Complete disinfestation through one application	Stop of the working activity during one day minimum

References

ADAM, B.D., PHILLIPS, T.W. AND P.W. FLINN, 2006: The Economics of IPM in Stored Grain: Why Don't More Grain Handlers Use IPM? - In: Lorini et al. (eds.) Proceedings 9th International Working Conference on Stored Product Protection, Campinas (Brazil), Brazilian Post-Harvest Association (publ.): 3-12.

ANONYMOUS, 2004: Regulation (EC) No 852/2004 of the European Parliament and of the Council of 29 April 2004 on the hygiene of foodstuffs, JO European communities Commission Brussels, Belgium.

ARTHUR, F., AND T.W. PHILLIPS, 2003: Stored-Product Insect Pest Management and Control. - In: Hui YH, Bruisma B, Gorham JR, Wai-Kit Nip, Tong PS and Ventresca P. (eds.) Food Plant Sanitation Marcel Dekker, Inc. New York 21: 340-361.

CAMPBELL, J.F., MULLEN, M.A. AND A.K. DOWDY, 2002: Monitoring stored-product pests in food processing plants with pheromone trapping, contour mapping, and mark-recature. - Journal of Economic Entomology **95**: 1089-1101.

CAMPBELL , J.F., PEREZ-MENDOZA, J. AND J. WEIER, 2012: Insect pest management decisions in food processing facilities. - In: Hagstrum DW, Phillips TW and Cuperus G (eds.) Stored Product Protection, K-State Research and Extension (publ.) **19**: 219-233.

COOK, S.M., KHAN, Z.R. AND J.A. PICKETT, 2007: The use of push-pull strategies in integrated pest management. - Annual Review of Entomology **52**: 375-400.

FLEURAT-LESSARD, F. 2011: Monitoring insect pest populations in grain storage: the European context. - Stewart Postharvest Review **7**: 3-5.

PHILLIPS, T.W. AND J.E. THRONE, 2010: Biorational approaches to managing stored-product insects. - Annual Review of Entomology **55**: 375-397.

PINNIGER, D. AND B. CHILD, 2002: Learning from museums-IPM in practice. - In: Credland PF, Armitage DM, Bell CH, cogan PM and Highley E. (eds.) Proceeedings 8th International Worrking Conference on Stored Product Protection, York (UK), CABI, Wallingford (UK): 248-251.

SCHÖLLER, M. AND P.W. FLINN, 2000: Parasitoids and predators. - In: Subramanyam Bh. and Hagstrum DW (eds.), Alternatives to pesticides in stored-product IPM, New York: Kluwer Academic Publishers: 229-272.

TREMATERRA, P., 2013: Aspects related to decision support tools and Integrated Pest Management in food chains. – Food Control **34**: 733-742.

TROLLER, J.A., 1993: Sanitation in Food Processing (2nd edition). - Academic Press, Inc., San Diego (CA): 263-286.

Abbreviations

EDT=Economic Damage Threshold; EU=European Union; FDA US=Food & Drug Administration; GMP =Good manufacturing practices; IPM=Integrated Pest Managment; IR=Infra-red radiation; HACCP=Hazard Analysis Critical Control Point; IMM=Indian meal moth; UV=Ultra-violet light

Static and Dynamic Stress Analysis of Flat Bottom-Bamboo Reinforced Concrete Silo for Rough Rice Storage

Lakshmi E. Jayachandran*, Pavuluri Srinivasa Rao

Agricultural and Food Engineering Department, Indian Institute of Technology Kharagpur
West Bengal 721302, India
*Corresponding author: lakshmiej90@agfe.iitkgp.ernet.in
DOI 10.5073/jka.2018.463.084

Abstract

Concrete silos are one of the most robust and reliable structures for grain storage in tropical countries. This study analysed the structural behavior of a low cost, flat bottom bamboo-reinforced concrete (BRC) silo for rough rice storage. This research included the design and development of a BRC silo in accordance with the guidelines mentioned by the Indian Standard (IS) codes. The Finite Element Method was employed to develop the stress profile in the silo walls under "grain at rest" and "grain filling" conditions. The results obtained were further compared with experimental results, classic silo theories (Janssen's theory) and standards of different countries in the world. The numerical technique gave stress magnitudes very close to those of the experimental results. The classic theories as well as the standards of different countries predicted an over estimation of the magnitude of stresses in the BRC silo. This would result in extra cost of construction of BRC silos. The study also suggested that the vertical stresses were most predominant under static and filling conditions. Maximum stresses were developed at the silo bottom. This study is expected to aid the development of economical silos with minimum wall thickness and material requirement which are ideal for on-site construction and use by smallholder farmers.

Keywords: Bamboo reinforced concrete silos, rough rice, finite element method, stress profile

1. Introduction

Food grain silos are highly efficient in storing bulk grains for a long period of time and safe from deteriorating agents such as rodents and insect pests. Modern silos are generally made of materials such as galvanized steel, reinforced cement concrete, painted Aluminum, plastic etc. If designed properly, these structures provide hermetic conditions ideal for safe storage of food grains, ensuring