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Food industry practices affecting pest management

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Purpose of review: This review highlights the most common practices in the dry food industry that may affect pest management programs. It also focuses on critical practices that may interfere with good integrated pest management (IPM) practices in food industry facilities and buildings.
Findings: Manufacturers of dry food products have a real challenge to exclude pests everywhere along the food chain because of the very 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 construction, 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 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.
Directions for future research: 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

Abbreviations

EDT	Economic Damage Threshold
EU	European Union
FDA	USA Food and 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

Introduction

Today, pest management practices in food industries are facing a tremendous obstacle to protect durable food products against pest infestation, because many markets have very low pest-induced damage tolerance and are also increasingly subject to intense scrutiny through external inspections and audits. There are also 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 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 that are vulnerable to insect pest infestation. Campbell *et al.* [1**], noted that food facilities differ from each other: in their activity or function (warehouse, mill, food processing plant, retail store, supermarket); in the concerned commodity (cereals, legumes, 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; and in their geographic location and surrounding landscape, etc. This makes it extremely complex and difficult to generalize about pest infestation risks because the 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 the food safety and hygiene levels required by global quality assurance systems (HACCP). Recent regulations, namely the EU Food Hygiene regulation package and the USA Food Safety Modernization Act of the FDA, are aimed at enforcing the application of HACCP to all food chains and in all plants, distribution centres, grocers and retail stores. This paper analyses practices, specifically in the dry food industry, that affect the risk level for pest infestation and decision-making processes for IPM, as related to HACCP system conception and implementation.

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 can influence pest management in food industries. Sanitation programs and the training of personnel to implement sanitation practices are essential.

Elimination of pest refuges and pest colony "nests"

Harbourage of insect colonies: In recent years, new methods of protecting the production cycle have been introduced for the

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prevention and control of pests. The filling or patching of crevices and cracks in floors and walls should be systematically done to limit accumulation of fine food material that attracts pests. Constant monitoring of insects with different techniques and careful attention of staff can prevent heavy infestations. For example, Lepidoptera and Coleoptera populations can be limited by: intensive trapping with pheromone and food traps: examining tracks in dust left on floors or machine craters; replacing wooden structures with metallic ones; sealing cracks and crevices in walls and floors; and replacing Archimedean screw conveyors with pneumatic (fluid-lift) conveyors. Some elements in building structures and machinery should also be changed or replaced (eg, gaskets). Crevices in which debris could accumulate must be sealed, and walls, edges and column floor junctions should be modified to prevent the accumulation of food particles.

Cleaning and hygiene maintenance: Today, large vacuum cleaners are used to eliminate accumulated dust; brooms and pressure cleaners must be banned. In fact, the removal of debris is more efficacious 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, very 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 need to be modified and staff trained to clean the least accessible areas. These areas are generally neglected and therefore sure sources of infestation, and, thus, are considered 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 directed to the importance of cleanliness and their duty to adhere to these recommendations.

Influence of physical condition control

Site location and structure type design: The maintenance of pest-free conditions in all areas of the site is an important action of an IPM program. 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. This is because concrete is more easily cleaned and weeds cannot grow on them. The basement walls of food plant buildings should be "insect proof" at the junction with the steel cladding of the building wall. This junction may be damaged from inside the building by impacts from pallet stacker trucks, which can give pests access to the food plant. Any damage that creates critical entry points for pests must be quickly repaired and there should be easy visual inspection of the entire exterior of the buildings. Where a new construction is being considered, an assessment of activities and the environment in proximity to the proposed site must be made. Landfill sites, watercourses, marshlands, derelict sites, and farms are all 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. Where an existing building is being renovated it must be taken into consideration what the building was previously used for since pests may still be resident. Thus, buildings that have previously been used in the food industry are most likely to have a pest history. A snagging list should be generated and dealt with before formal receipt of a new building or extension. 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-conditioned workshops: The population dynamics of stored product insect pests such as meal moth or flour beetles - which are common species in food industry facilities - is at their optimum in the range from 25 to 30°C. In factories producing cooked products (such as biscuits or bread), ambient temperature may be in this range all year, especially in the rooms where cooking ovens produce heat. These areas have an increased risk of insect pest presence such as Indian Meal Moth (IMM) which may lay eggs after cooking while the product is cooling. The associated risk is easily identified; for example, when a conveyor belt covered with cooling biscuits stops (because of a technical issue), cooled biscuits are available to IMM females for egg deposition. One solution to this issue is to cool the food production areas below the lower threshold of moving activity of flying insects (IMM or flour moths or the drugstore beetle, *Stegobium paniceum* (L)), ie, below 15°C. Below this lower limit, insects remain quiet and do not lay eggs on the produce before wrapping (eg, biscuits) and packaging. Consequently, it is recommended to use air conditioning (lower than 14-15°C) in production areas to inhibit insect movements.

Internal and external lightening of the buildings: The type of lighting at a site will, to a certain extent, determine the attractiveness of the site to flying insects or other pests. Most attractive are mercury-vapour lamps and special fluorescent lamps used for perfect colour rendition. Next are "ordinary" commercial and household fluorescent tubes. The warmth of IR 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, lights should be positioned five or six 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 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. The power conduit for external lights must be designed so that it does not provide roosting or nesting sites for nuisance birds. White or light yellow surfaces of building should be avoided due to their ability to reflect UV light. This should be considered when deciding the overall building colour scheme but can, however, be relevant to smaller scale studies such as the colour of surfaces around entryways. 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 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 prevent waterlogged soil. Certain insect pests (eg, 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 and direct contact of tree leaves and branches with the exterior wall of the facility should be systematically prevented, 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, mice and various pest birds. Shrubs and trees should be of a coniferous type (releasing odour 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 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 coverage 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. Rainwater downpipes are easy ways for rodents to climb near the roof of the buildings to reach the space between the roof and the wall existing in numerous buildings.

Risks related to building structure design: Regarding building structure, 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 one metre above ground level to prevent rodents climbing external walls. Airbricks supply ventilation to walled cavities but they may also 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 night time roosts for pest bird species. For the same reason over-developed external wall facia 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. Specific advice for these details in construction design are available from Troller [2*].

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 (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 with places that are hard to reach for regular cleaning, for example roofs or ceilings that are high, accumulate dust and debris, and serve as a harbourage 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 and birds rely on a supply of drinking water, sources of free water should be avoided. Any pools on concrete bases 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 downpipes should be fitted externally, rodent entry into a downpipe from the ground can be prevented by the use of a back inlet gully. Pipes and cables: ie, 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 propped 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 advised. 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 insects 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 night time roosts. Ceiling voids are potential harbourages for pests. Enclosed voids can also make inspection for pests difficult. More generally, industry practices leading to negligence and lack of common sense, like "keeping doors and windows open for aeration" allow access to insects. GMP compliances for point of entries and common sense practices can eliminate pest infestation.

Storage 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 prevent insect colonies from forming in such protected locations. Adequate space between racking bays should also 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 preferable 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 pallets in plastic material. Storage shelving should not have concealed cavities. If spillages cannot be cleaned easily, pests may make use of them to conceal their harbourages. Cleaning of floors and walls 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, so that raw ingredients never cross the processed or semi-processed food line. Because insect pest development can be completed in one month in indoor conditions, raw food commodities must not be kept for the minimum period of time in storage. So, in all storage rooms, the product flow must comply with the principle "first in, first out" so that the stock rotation is as short as possible. There is a great need to ensure a sanitary environment in the chain for dry food product processing.

Cleaning material and equipment: The prevention of infestation issues in food processing lines is closely related to cleaning effectiveness and regularity after the detection of insect outbreaks and emerging issues in conveyors belts or in equipment and machines. Cleaning should focus on ingredients and dough fragments that have fallen down and accumulated below the conveyor belts or are stuck on belt support rollers. All residues in machinery should be removed regularly (eg, each day) and the whole machinery thoroughly cleaned after each change in product type or before long shut-down periods. Food products waiting on a stopped conveyor belt for more than half an hour should be immediately removed and should not 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 [3].

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. For example, corrugated cardboard material temporary stored in a food processing area may be the perfect refuge for migrant larvae of the IMM.

Isolation and treatment of infested commodities and out-of-use material: 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 remain attractive to flying pests because of food product or food dust deposit inside. This "out-of-use "equipment should be rapidly removed 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 odour. This permeability to food odour is a common weakness of a lot of inexpensive 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 (eg, IMM, *Plodia interpunctella* (Huebner)) or by rodents. Additionally, certain types of package (cardboard cassette and boxes with flexible pouring spout or bags with wide apertures that do not reseal) are no longer able to prevent insect entry after first opening.

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 far away from walls (30 – 50 cm) to allow free access to the area behind for inspection and cleaning. Strict separation is required between raw materials, food processing areas, finished food products, and the 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 situated 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 programms, but once in place, it can be used to make more reliable pest management decisions. Unfortunately, many of the studies reported in literature have been achieved under laboratory conditions, so there is limited information on their integration under field conditions. Studies in simulated food factories have illustrated that it is difficult to impact populations in hidden refuge with biocide applications not applied directly to the food patches, and that trap captures to evaluate the impact of treatment did not always reliably track changes in pest populations. This situation leads to a difficult appreciation by food quality managers of the economical damage threshold (EDT) from which corrective measures to control a latent infestation have to be implemented. Yet, the IPM strategy is based on corrective intervention in dependence to 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 an IPM is limited. An IPM program is an evolving process that applies local intelligence and responds to changing needs [4]. 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. In many cases, the gap between IPM research and practical management remains large.

Strengthening pest monitoring programs for food industry

The success of an IPM program in food industry is highly dependent on an effective monitoring system that supplies information useful for translating the number and type of insect catches in traps into practical knowledge about changes of populations over time and location of foci of infestation, as well as the routes of entry [5]. Thus, insect monitoring is a primordial component of pest management in food processing plants [6**]. 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, the use of predictive models of pest population density changes over time, and the feeding of expert systems to determine the best time and way to suppress pest populations [7**, 8**]. 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 [1, 7**]. Currently, computer simulation models are available primarily for insect pests of stored grain, but in the future such models should be particularly useful in decision-making for pest management strategies in dry food processing and marketing chains.

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

As stated by Adam *et al.* [9] 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 personnel implication, minimum required knowledge, difficulty adopting a new technology, pressure of pesticide supplier or fumigation company, etc. Limited acceptance of IPM in food facilities can be 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 (Table 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: Differences exist between bulk-stored commodities and other parts of the food chain. 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) [7**]. 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.

Biocontrol agents difficult application 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 [32**, 33*]. A summary of the more promising modern tools that may be integrated to IPM programs for the food industry is described in Table 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.

Further research needs for larger implementation of IPM in 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 [34]. 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) while 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 site, 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 prevision and prevention should become accessible to food industry quality managers in the near future.

References

Papers of interest have been highlighted as:
* Marginal importance
** Essential reading

1 Campbell JF, Perez-Mendoza J and Weier J. Insect pest management decisions in

Table 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	Reference
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	[8, 10]
		Localisation of loci of pest infestation by contour mapping from trap catches	Accurate location of infested goods	Weekly trap data processing	[1, 10, 11]
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 for food bag or box testing insect proof properties	[12]
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	[13]
		Permeation of food facility atmosphere with pheromone for mating disruption or self-confusion	Effective against flying insects	Slow reduction of pest population expensive renewal of dispensers	[14]
		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	[15–17]
		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	[18, 19]
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	[20, 21]
		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	[22]
		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	[23–26]
		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 (eg, medicinal plants and spices)	[27, 28]
		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 single 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 small number of active substances	[24, 29]
		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	Stopping of the working activity during one day minimum	[30, 31]

food processing facilities. *In*: Hagstrum DW, Phillips TW and Cuperus G (eds.) Stored Product Protection S156, KS Research and Extension (publ.). 2012: 19: 219-233.

**This book chapter is an updated review of current practice of IPM implementation in food processing plants, from IPM principle application to responsive treatment based on decision-making from action thresholds.

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

* This book chapter provides illustrated information on how to design all structure and interior equipment of a food processing plant in order to limit pest multiplication sites.

3 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.

4 Pinniger D and Child B. Learning from museums-IPM in practice. *In*: Credland PF, Armitage DM, Bell CH, Cogan PM and Highley E. (eds.) Proceedings 8th International Working Conference on Stored Product Protection, York (UK), CABI, Wallingford (UK) 2002: 248-251.

5 Burkholder WE. Practical use of pheromones and other attractants for stored product insects. In: Ridgway RL, Silverstein RL, Inscoe MN (Eds.) Behaviour modifying chemicals for insect management: application of pheromones and other attractants. Marcel Dekker, New York, 1990: 497-516.

6 Campbell JF, Mullen MA and Dowdy AK. Monitoring stored-product pests in food processing plants with pheromone trapping, contour mapping, and mark-recapture. Journal of Economic Entomology 2002: 95: 1089-1101.

**This article details how to apply the interpretation of trap catches through contour mapping for localization of the stored product insects multiplication site in large food plants.

7 Fleurat-Lessard F. Monitoring insect pest populations in grain storage: the European context. Stewart Postharvest Review 2011: 7: 3:5 doi: 10.2212/spr.2011.3.5

**This recent review provides details on all the methods and tools usable for monitoring insect populations changes in bulked grain and storage facilities.

8 Arthur F, Phillips TW. 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 2003:21: 340-361.

**This book chapter is an exhaustive review which provide very useful details on sanitation methods and various insect pest monitoring strategies in food plants

9 Adam BD, Phillips TW and Flinn PW. 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.) 2006: 3-12.

10 Arbogast RT, Kendra PE, Chini SR and McGovern JE. Meaning and practical value of spatial analysis for protecting retail stores. *In*: Credland PF, Armitage DM, Bell CH, Cogan PM and Highley E. (eds.) Proceedings 8th International Working Conference on Stored Product Protection, York (UK), CABI, Wallingford (UK) 2002: 1033-1038.

11 Trematerra P and Sciarretta A. Spatial distribution of some beetles infesting a feed mill with spatio-temporal dynamics of *Oryzaephilus surinamensis*, *Tribolium castaneum* and *Tribolium confusum*. Journal of Stored Products Research 2004: 40: 363-377.

12 Mullen MA. Rapid determination of the effectiveness of insect resistant packaging. Journal of Stored Products Research 1994: 30: 95-97.

13 Weier JA. Value of spatial analysis in pest management, from the perspective of the pest control operator. *In*: Credland PF, Armitage DM, Bell CH, Cogan PM and Highley E. (eds.) Proceedings 8th International Working Conference on Stored Product Protection, York (UK), CABI, Wallingford (UK) 2002: 1028-1032.

14 Mohandass S; Arthur FH, Zhu KY and Throne JE. Biology and management of *Plodia interpunctella* (Lepidoptera: Pyralidae) in stored products. Journal of Stored Products Research 2007: 43: 302-311.

15 Shuman D, Weaver DK and Mankin RW. Quantifying larval infestation with an acoustic sensor array and cluster analysis of cross-correlation outputs. Applied Acoustics 1997: 50: 279-296.

16 Fleurat-Lessard F, Tomasini B, Kostine L and Fuzeau B. Acoustic detection and automatic identification of insect stages activity in grain bulks by noise spectra processing through classification algorithms. In: Lorini I *et al.* (Eds.), Proceedings 9th International Working Conference on Stored Product Protection, Campinas, Brazil, 15-18 October 2006: 476-486.

17 Leblanc M-P, Gaunt D and Fleurat-Lessard F. Experimental study of acoustic equipment for real-time detection of insects in grain bins – Assessment of its potential for infestation risk prediction during long-term storage periods. Proceedings IOBC-WPRS Conference, Campobasso, Italy, July 2009, IOBC/wprs Bulletin 2011: 69: 79-88.

18 Driscoll R, Longstaff BC and Beckett S. Prediction of insect populations in grain storage. Journal of Stored Products Research 2000: 36: 131-151.

19 Beckett SJ, Longstaff BC and Evans DE. A comparison of the demography of four major stored grain coleopteran pest species and its implications for pest management. In: Highley E, Wright EJ, Banks HJ and Champ BR (eds.) Proceedings of 6th International Working Conference on Stored Product Protection, Canberra, April 17-23, 1994, vol. I: 491-497.

20 Trematerra P. Advances in the use of pheromones for stored-product protection. Journal of Pest Science 2012: 85: 285-299.

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

**This article describes the complex decision-making process in using pest monitoring data before responsive treatment implementation within the frame of IPM programs.

22 Dowdy AK and Fields PG. Heat combined with diatomaceous earth to control the confused flour beetle (Coleoptera: Tenebrionidae) in flour mill. Journal of Stored Products Research 2002: 38: 11-22.

23 Lord JC. Desiccation increases the efficacy of *Beauveria bassiana* for stored-grain pest insect control. Journal of Stored Products Research 2007: 43: 535–539.

24 Kavallieratos NG, Athanassiou CG, Michalaki MP, Batta YA, Rigatos HA, Pashalidou FG, Balotis GN, Tomanović Z and Vayias BJ. Effect of the combined use of *Metarhizium anisopliae* (Metschinkoff) Sorokin (Deuteromycotina: Hyphomycetes) and diatomaceous earth for the control of three stored-product beetle species. Crop Protection 2006: 25: 1087-1094.

25 Athanassiou CG, Kavallieratos NG, Vayias BJ, Tsakiri JB, Mikeli NH, Meletsis CM and Tomanović Z. Persistence and efficacy of *Metarhizium anisopliae* (Metschnikoff) Sorokin (Deuteromycotina: Hyphomycetes) and diatomaceous earth against *Sitophilus oryzae* (L.) (Coleoptera: Curculionidae) and *Rhyzopertha dominica* (F.) (Coleoptera: Bostrychidae) on wheat and maize. Crop Protection 2008: 27: 1303-1311.

26 Cavoski I, Caboni P and Miano T. Natural pesticides and future perspectives. In: Stoytcheva M (ed.) Pesticides in the Modern World – Pesticide Use and Management. InTech Europe Publisher, Rijeka, Croatia 2011: 169-190. http://www.intechopen.com/books/

27 Dupuis SA, Fuzeau B and Fleurat-lessard F. Feasibility of French beans disinfestation based on freezing intolerance of post-embryonic stages of *Acanthoscelides obtectus* (Say) (Col.: Brucidae). *In*: Lorini et al. (eds.) Proceedings 9th International Working Conference on Stored Product Protection, Campinas (Brazil), Brazilian Post-Harvest Association Publ. 2006: 956-965.

28 Vincent C, Weintraub P, Hallman GJ and Fleurat-Lessard F. Insect management with physical methods in pre- and post-harvest situations. *In*: Radcliffe EB, Hutchison WD, Cancelado RE (Eds.) Integrated Pest Management, Cambridge University Press, Cambridge (UK) 2009: 309-323.

**The authors review the principles of IPM application to postharvest insect population control using physical control methods and classical monitoring tools.

29 Kavallieratos NG, Athanassiou CG, Vayias BJ, Kotzamanidis S and Synodis SD. Efficacy and adherence ratio of diatomaceous earth and spinosad in three wheat varieties against three stored-product insect pests. Journal of Stored Products Research 2010: 46: 73-80.

*This article is presenting the complexity of the use modern tools of biocontrol (myco-insecticide) to the case of stored product insect control.

30 Subramanyam Bh, Mahroof R and Brijwani M. Heat treatment of grain-processing facilities for insect management: a historical overview and recent advances. Stewart Postharvest Review 2011: 3: 1, doi: 10.2212/spr.2011.3.1

*This article is presenting the potential of heat treatment disinfestation of grain-processing plants with a history of the renewal of this old practice of mill disinfestation as the main alternative to methyl bromide fumigation.

31 Vacquer B, Lethuillier L, Brunel M, Fraterno R and Fleurat-Lessard F. First application in France of heat disinfestation of a large wheat mill. 9th Conference IOBC/WPRS on Integrated Protection of Stored Products, Bordeaux, France, 01-04 July 2013, IOBC/wprs Bulletin 2014: 98: 243-251.

32 Phillips TW and Throne JE. Biorational approaches to managing stored-product insects. Annual Review of Entomology 2010: 55: 375-397.

**This exhaustive review is a comprehensive description of all the methods and techniques using biorationals and biological agents usable in IPM programs for the control of stored product insect pests, including innovative techniques still under research.

33 Schöller M and Flinn PW. Parasitoids and predators. *In*: Subramanyam Bh. and Hagstrum DW (eds.), Alternatives to pesticides in stored-product IPM, New York: Kluwer Academic Publishers 2000: 229-272.

*The authors highlight the potential of biological control in stored-product pest control programs.

34 Cook SM, Khan ZR and Pickett JA. The use of push-pull strategies in integrated pest management. Annual Review of Entomology 2007: 52: 375-400.