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Review Article

Management strategies for storage, disinfestation and insect detection of grains and seeds

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ABSTRACT : Agricultural products such as grains are the major source of food for human and most domesticated animals. In many developing countries, overall postharvest losses of cereals and legumes about 10–15% are quite common. Consumption of cereals and legumes by pests such as insects during storage and microbial spoilage or contamination may make these totally inedible. During storage, quantitative as well as qualitative losses occur due to insects, rodents, and micro-organisms. For protection of grain damage and quality of food grains, various storage and disinfestation methods are used. Natural contamination of food grains is greatly influenced by environmental factors such as type of storage structure, pH, temperature, moisture, etc. At any given time 60-70% of grains are stored on the farm in traditional structures like jute sacks, baskets, earthern pots, metal drum and underground pits. Few important disinfestation methods such as microwave, gamma ray,infra-red and radio frequency energy, pheromone baited traps, and use of entomopathogens proved highly effective against stored grain insects. Besides this, aeration cooling and low temperature treatments proved much safer pest management tools that represent a potential alternative of fumigants to control insects. Further development of various detection technologies such as acoustic detection, X-rays images, near-infrared (NIR). Spectroscopy and electronic nose is the promising tool for detection of insect.

KEY WORDS : Qualitative loss, Quantitative loss, Disinfestation, Infra-red energy, Electromagnetic radiation, Aeration cooling, Acoustic detection, X-rays imaging, Electronic nose, NIRS

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INTRODUCTION

The storage of agricultural products such as seed and grain has been an age long practice with traders and cultivators. More pest-free storage is needed for handling crops at harvest time and to carry over reserves from year to year. Substantial losses both in quality and quantity of agricultural products take place in storage due to a number of factors.It is estimated that 5-10 per cent of the stored grain is lost every year due to insect andinadequate farm and village-level storage-damage in India and about 30 per cent worldwide. According to World Bank Report, post-harvest losses in India amount to 12 to 16 million metric tons of food grains each year, an amount that the World Bank specifies could feed one-third of India's poor. The economic value of these losses amounts to more than Rs 50,000 crores/ year (Singh, 2010).

Most developing countries are in the tropics, often in regions of high rainfall and humidity. These conditions are model for the growth of micro-organisms and insects which cause high levels of deterioration of crops in store. The food losses during storage are the result of biological damage (by insects, rodents and micro-organisms), chemical damage

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(through rancidity development and flavour changes) or physical damage (through crushing, breaking etc.).Some examples of the major insect pests of stored grain are *Rhyzopertha dominica* (lesser grain borer), *Oryza ephilus surinamensis* (saw toothed grain beetle), *Sitophilus oryzae* (rice weevil), *Trogoderma granaria* (khapra beetle), *Tribolium castaneum* (red flour beetle) and *Plodia interpunctella* (Indian meal moth). In order to minimize the losses during storage it is important to know the optimum environmental conditions for storage of the product, as well as the conditions under which its attackers thrive.

Conditions for seed storage:

The period for which seed can remain viable without germinating is seriously affected by its quality at the time of collection, the conditions in which it is stored and its treatment between collection and storage. However, seed endurance varies enormously from species to species even if they are given identical treatment and storage conditions. Ewart (1908) divided seeds into three biological classes microbiotic (seed life span not exceeding 3 years), mesobiotic (seed life span from 3 to 15 years) and macrobiotic (seed life span from 15 to over 100 years).

There two major classes of seed are:

Orthodox:

Seeds which can be dried down to a low moisture content (MC) of around 5% (wet basis) and successfully stored at low or sub-freezing temperatures for long periods.

Recalcitrant:

Seeds which cannot survive drying below relatively high moisture content (often in the range 20–50% wet basis) and which cannot be successfully stored for long periods.

Low MC, low temperature and low oxygen pressure as the three most important constituents of the storage conditions which man should provide to maximize seed longevity in orthodox species. Unlike orthodox species, in which viability is best preserved by maintaining a minimal respiration rate, it shows that active respiration is necessary to survival of seeds of most recalcitrants. Hence, damage to recalcitrant seeds has been reported not only from inadequate MC and too low a temperature but also from lack of oxygen. The high viability of recalcitrant seeds could be maintained for at least 6 months by storage at 3.5°C and high MC; 37% was significantly better than 32%.

For seeds with a moisture content between 5 and 14% every 1% decrease in moisture content doubles the possible storage time. Below 5% oxidation processes may play a role. Above 14% fungal growth causes rapid degeneration. Every 5^0 C decrease of the storage temperature doubles the possible storage time. The time of harvesting is very important for prolonged preservation of the seed viability. Seed that is harvested when still unripe loses its viability more rapidly than well-ripened seed.

Conditions for grain storage:

Food grains form an important part of the vegetarian Indian diet. Natural contamination of food grains is greatly influenced by environmental factors such as type of storage structure, pH, temperature, moisture, etc. (Sashidhar *et al.*, 1992). High temperature and high moisture are the most significant factors affecting grain quality in storage. Each can cause rapid decline in malting quality, baking quality, germination, colour, oil composition, and many other quality characteristics. When dried to moisture contents below the safe moisture level, pulses and cereals can be stored for periods of a year or more under a wide range of temperatures, on condition that during storage the moisture level does not rise, and safety measures against insects are taken. Insects and moulds impair the quality of grain directly by their feeding and development, and indirectly through generation of heat and moisture. Development of insects is limited by temperatures below 15°C, and by moistures below 9% in cereal grains. Development of moulds is limited by temperatures below 10°C, and by moistures below 13% in cereal grains.

Table 1 : The safe moisture content for any particular grain may vary slightly depending on the variety (valid for about 27 °C)

Sr. No.	Safe moisture product	Content (%)
1.	Cereals: Maize (shelled)	13.5
	Maize flour	11.5
	Paddy rice	15.0
	Milled rice	13.0
	Sorghum	13.5
	Millet	16.0
	Wheat	13.5
	Wheat flour	12.0
2.	Pulses: white and kidney bean, broad bean, cowpea	15.0
	Lentil, pea	14.0

Storage and disinfestation strategies:

The process of respiration within stored products is a topic that has been researched since the 1920s. Respiration is the process in which oxygen is utilized in the breakdown of carbohydrates, and then energy is released. When fungal growth occurs within the stored product, continuous respiration releases carbon dioxide (CO_2), water and heat. These three products can be used to detect deterioration in a stored product; but, of the three, temperature has been accepted as the standard method by the grain industry (Ileleji *et al.*, 2006). The rate of respiration is reduced approximately by one half for each 10°C reduction in temperature. During storage, quantitative as well as qualitative losses occur due to insects, rodents, and micro-organisms. Weevils and grain beetles feed on grain in both the adult and larval stages. Also, the larvae of several types of moths attack the seeds. Apart from the actual losses caused by feeding, storage insects promote mold and spoilage of grain by increasing temperature and adding moisture. A heavy infestation can increase grain moisture content by 5-10 per cent within several months. Most of the insects that affect stored grains develop most rapidly at temperatures between 25 and 30^0C and a relative humidity in between 70 and 80%. However, they may still develop, although at a lower rate, at lower or higher temperatures and relative humidity.Early recognition of an infestation is very important for reducing potential grain losses. Stored grain should be directly checked every several weeks for sign of an insect buildup.

Strategies for storage of grain or seed:

The storage methods range from mud structures to cement silos. The containers are made from a variety of locally available materials differing in shape, size, design and functions. The materials used include wheat straw, reeds, paddy straw, wood, bamboo, mud, bricks, cow dung etc. Grains can be stored indoors, outdoor or at underground level (Channal *et al.*, 2004).

Earthenware pots and gourds:

These are hard, dried outside cases of certain fruits or vegetables. It is useful for storing small quantities of cereals, beans, groundnuts, and also for the storage of sowing seed.By treating the pots and gourds with varnish, paint or linseed oil, and sealing the lids with mud or cowdung an airtight form of storage is obtained.

Baskets:

It is a grain storage container made up of bamboo. The base is usually round and has a wide opening at the top. Baskets do not give enough protection against insects, but this can be improved by applying mud, clay or cowdung to the in- and outside. The outside layer of mud also gives protection against rodents. With this storage method it is possible to use insecticides mix with the grain.It is suitable for cereals, pulses, oil containing seeds and potatoes.

Jute sacks:

Sacks made up of jute, sisal, cotton, hemp or other locally available fibresare easy to handle and label. These sacks allow gasses to pass through and therefore insects may be controlled by using fumigants in a closed room or underneath a plastic sheet covering the stack.The fibre sacks do not give much natural protection against insects, rodents, fungi and moisture. They are also easily damaged during transport and handling. It is suitable for storing sowing seed, cereals, pulses and groundnuts.

Earthen silos:

Earthen silos are constructed with a large door for pouring grains. An outlet is made for taking out the grains. They are less suitable for the wet tropics because moisture may enter via the walls, which increases the chance of fungal growth. The product to be stored should be well dried before putting it in the silo. They are cheap, can be built with local materials clay or mud, bamboo or wood, and straw or grass for traditional types and skilled labor is not needed. It is suitable for cereals, oil crops, pulses and yams storage for a period of 6-9 months.

Metal drums/ silos:

They can be used in the dry and humid tropics. The drums should never be placed in direct sunlight because of the dangers of the product becoming caked to the inside wall, of moisture changes and heating of the stored product. They should either be placed under a good roof or should be insulated with a layer of straw. They are suitable for storage of cereals and pulses for one year.

Brick and cement silos:

Brick and ferrocement silos can be built in many forms and sizes. The walls are made of cement staves, pressed together with iron wire, and the cover slab is made of concrete. These silos are suitable for both the dry and the wet tropics. They should be protected from rain by a roof and by a bottom floor made of (reinforced) concrete or (fired) bricks. They are suitable for storage of cereals and pulses for about one year and its capacity varying with types.

Underground pit:

Underground pits (Fig. 1) are an effective, low-cost method of long-term grain storage. Feed grain has been recovered in good condition after more than 10 years. The main drawback of underground storage is the difficulty of removing grain. The method is successful only if careful precautions are taken. Grain moisture content must be less than 12% to keep the risk of spoilage low. The pit should not be more than three metres wide. The roofing of the pit can be made of metal sheeting, sealed with mud/dung or bitumen, or polythene sheeting. Well-constructed pit storage is air-tight and oxygen levels gradually reduce over time. The low oxygen levels prevent development of damaging numbers of grain insects. If in doubt about the gas-tightness of the pit, grain protectants can be applied to the grain when it is placed in storage.

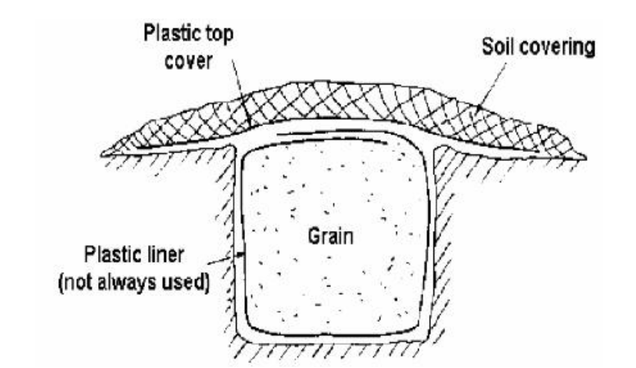

Fig. 1 : Cross section of underground pit storage

Pusa bin:

The Indian Pusa bin is a square silo, double-walled all the way round - including the floor and roof - with a separating layer of plastic sheet between the walls. The plastic protects against moisture and keeps air from entering the stored product, provided the fill- and outflow openings can be tightly closed. The walls are made of mud blocks, but can also be made of mud (90%) mixed with cement (10%), fired bricks or concrete. It is suitable for the dry and wet tropics, provided it is protected from rain. It gives good protection against insects and rodents, especially if the bottom 50 cm of the outside walls and the bottom layer are made of fired bricks or concrete.

CAP storage:

CAP Storage (Cover and Plinth) involves the construction of brick pillars to a height of 14" from the ground, through grooves into which wooden crates are fixed for the stacking of bags of food grains. The stacks are enveloped with 250 micron LDPE sheets from the top and all 4 sides. Food grains such as maize, wheat, gram, sorghum, and paddy are generally stored in CAP (cover and plinth) storage for 6-12 month periods. It is the most inexpensive storage structure and is being extensively used by the FCI for bagged grains. The structure can be manufactured in less than three weeks. It is an economical way of storage on a large scale (www.indiaagronet.com/).

Warehouses:

Warehouses are scientific storage structures especially constructed for the protection of the quantity and quality of stored products in bulk quantity. The warehouses are owned by CWC, FCI or the SWCs. The Central warehousing corporation (CWC) was established as a statutory body in 1957. Separate warehousing corporations were also set up in different States of the Indian Union. The regions of operation of the State Warehousing Corporations (SWCs) are centres of district importance. Food Corporation of India (FCI) is the single largest agency which has a capacity of 26.62 million tons (*www.indiaagronet.com/*).

Strategies for controlling stored grain insects:

Controlling by biological components:

Plant's leaves/ashes:

In some areas, certain plants are known to have insecticidal properties and are mixed with the grain (Rahmanand and Talukder, 2006).

Vegetable oil:

The oils of cottonseed, peanuts, sesame, and mustard and coconut seed have given excellent protection from bruchid infestation in beans and cowpeas when added at the rate of 0.5-1.0 per cent (5-10 ml per kg of seed.) safety lasts for up to 6 months and does not affect the physical appearance of the grain since it is absorbed. Volatile compound diallyldisulphide isolated from neem have shown powerful toxic, fumigant and feeding deterrent activity against stored grain pests, *Sitophilusoryzae* and *Tribolium* plant volatile aldehydes are used as natural *castaneum* (Koul, 2004).

Spinosad:

Spinosad is a commercial biological insecticide produced by fermentation culture of actinomycete *Saccharopolysporaspinosa*. To evaluate the effect of spinosad in controlling stored grain pests, the touch effects of 2.5% spinosad were tested in the laboratory on three main stored grain insects *L. entomophila*, *Oryzae philussurinamensis* (L.), and *S. oryzae*. Results indicated that spinosad is effective in pest control for the three insects, more effective for *L. entomophila* than the other two insects (Cao and Qi, 2007).

Microbial control:

Microbial spores and toxins are used as insecticides. It is much safer and highly specific toxins. Most effective strain is Bt toxins produced by *Bacillus thuringensis*, is utilized against stored grain insects. In addition to this, many entomopathogens are used for the control of stored garin pests (Diaz-Gomez *et al.,* 2000).

Insect pheromones:

Pheromones of *Trogoderma* and the black carpet beetle, *Attagenusmegatoma* are used in inducement traps to capture these insect pests in larger number. The primary component of the *Trogoderma* pheromone, 14- methyl 8 - hexadecenal is now used to capture and kill large numbers of *Trogoderma granarium*. Besides this, wheat germ oil combined with sex pheromone is used to attract and trap *Trogoderma* larvae.

Similarly, male lesser grain borer, *Rhyzoperthadominica* (F.), produce an aggregation pheromone that attracts both sexes. In addition to this, synthesized pheromones are used in baited traps, which were found efficient in monitoring populations (Kaakeh, 2000).

Controlling by chemical components:

Insecticides:

Some insecticides like malathion, lindane, actellic and pyrethrins can actually be mixed with food grain without harmful effects or residues if used correctly. Many other insecticides would make the grain very toxic and unsuitable for consumption.

Fumigation:

Fumigation is a long established and effective method for the control of stored-product insects in flour mills. Fumigants such as methyl bromide, phosphine, sulfuryl fluoride (ProFume™) and carbonyl sulphide are effective disinfectant. However, since January 2005, many uses of methyl bromide have been banned in developed countries because, on entering the atmosphere, it is a powerful ozone depleter (Fields and White, 2002) by by the U.S. Environmental Protection Agency (EPA) under the Federal Clean Air Act (Browner, 1999) and the Montreal Protocol (UNEP, 2006).

Inert dusts, sands and silica aerogel:

Sands and soil components were also used as traditional insecticides. Sands give protective layer on top of stored seed. Besides this, fossilizized remains of diatoms known as diatomaceous earth (DE) were also used to protect food grains. Besides natural DE arttficially modified CaDE are also being made which have shown insecticidal repellent and ovicidal activity against *Callasobruchu* s*maculates*. Similarly silica aerogel that contain sodium silicate is used as a non-hygroscopic powder to control field and store grain insects (Quarles, 1992).

Controlling by physical components :

Sun drying:

Beetles and weevils will leave grain if it is placed in the hot sun in a superficial layer. However, this typically will not kill all the eggs and larvae inside the kernels. Sun drying is a common farming and agricultural process in various countries, particularly where the outdoor temperature reaches 30° C or higher. In many parts of South East Asia, spice herbs and crops are routinely dried. Warm, dry, moving air encourages more rapid drying to lower moisture content than cool, still and damp air. In fact, if the air becomes excessively damp, grain may actually begin to absorb moisture and become wetter (Chua and Chou, 2003).

Aeration cooling:

Freshly-harvested grain usually has a temperature around 30°C, which is an ideal breeding temperature for storage pests. Studies have shown that rust-red flour beetles stop breeding at 20°C, lesser grain borer at 18°C and below 15°C all storage pests stop breeding.Aim for grain temperatures of less than 23°C during summer and less than15°C during winter.When placing grain into storage, run aeration fans continuously for the first 2-3 days to push the first cooling front through the grain and to create uniformmoisture conditions. Then run the fans during the coolest 9-12 hours per day for the next3-5 days. This will push a second cooling front through the grain bulk. Aeration cooling usually only requires air-flow rates of 2-4 litres per second per tonne.

Low and high temperature:

Grain temperature raised upto 55-65°C and for10 to 12 h can effectively kill all life satges of stored grain pest in ware houses. Similarly low temperature also provides long term effect on stored seed and keeps them free of insect infestation. Low temperature reduces insect development and kills large number of immature stages of stored grain insects. The insects become inactive andeventually die at a temperature below 12 °C. Low temperature also maintains seed viability (Aspaly *et al.*, 2007).

Controlling by electromagnetic rays:

Infra-red radiation:

Among currently used thermal processes, those using electromagnetic waves find their wide application. Knowledge on their specific interaction to biological materials may contribute to the improvement of known or elaboration of new technologies for processing a wider and wider spectrum of plant-originated materials (Rai, 2002). Fast reduction of moisture content, *i.e.* drying, is a result of thermal processing using IR (Grochowicz, 1997). It changes physical and chemical properties of final products, which is important during transport, storage, breaking, dehulling, agglomerating, etc. (Dariusz and Andrejko, 2005). A study was aimed at evaluating the influence of thermal processing parameters in the form of IR radiation on selected physical properties (moisture content and compressing strength) at wheat grains conducted by Andrejko *et al.* (Dariusz, 2007). Ceramic IR radiator (ECS-1 type) of 400 W powers was selected as a source of IR radiation (Elcer). It is a temperature radiator supplied by electricity (230 V), and having in its spectrum the share of visible radiation at the level of small fraction (dark radiator), and uniformly warming all plane points (plane radiator). Average temperature of filament surface is about 500°C, and wavelength λ=2.5-3.0 μm. Temperature and duration the wheat grains are exposed in IR radiation are factors that significantly affect the amount of evaporated water. Increasing the temperature from 100°C to 180°C and elongating the heating time from 30 to 150 sec., the decrease was observed in moisture content of wheat grains subjected to IR radiation processing.

Radio frequency (RF) energy:

Radio frequency (RF) energy offers the possibility of rapidly increasing temperatures inside bulk materials. Hence, there has been an increasing interest in developing advanced thermal treatments for postharvest insect control in legumes using this method. RF energy directly interacts with commodities containing polar molecules and charged ions to generate heat volumetrically and significantly reduce treatment times as compared to conventional heating methods. A pilot-scale 27 MHz, 6 kW RF unit (Fig. 2) was used (Wang, 2012) to investigate RF heating and consequent quality attributes in treated chickpea, green pea, and lentil samples (Jiao *et al.,* 2012). Only 5–7 min were needed to raise the central temperature of 3 kg legume samples to 60˚ C using RF energy, compared to above 275 min when using forced hot air at 60˚ C. RF heating uniformity was greatly improved by 60˚ C forced air and movement of the container between the electrodes. For all three legumes the effects of hot air and RF treatments on color and germination were negligible, which are in good agreement with the germination in lentils. RF treatments, therefore, should offer a practical, efficient and environmentally friendly method for disinfestation of postharvest legumes while maintaining product quality. The RF treatment developed by Wang *et al.* (2007), was also very effective for controlling Indian meal moth, codling moth and red flour beetle in in-shell walnuts (Wang *et al.,* 2007).

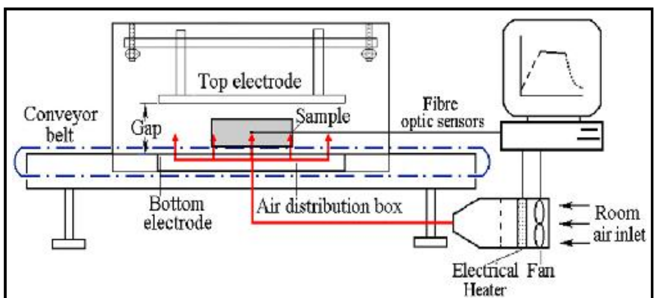

Fig. 2 : Schematic view of the pilot-scale 6 kW, 27.12 MHz RF unit showing the two-pair plate electrodes, conveyor belt and the hot air system used by Wang *et al.*, 2010

Microwave energy:

Microwaves are electromagnetic waves with frequencies ranging from about 300MHz to 300GHz and corresponding wavelengths from 1 to 0.001m (Decareau, 1985).Microwave heating is based on the transformation of alternating electromagnetic field energy into thermalenergy by affecting polar molecules of a material. The most important characteristic of microwave heating is that materials absorb microwave energy directly and internallyand convert it into heat (Mullin, 1995). The use of microwaves to kill insects is based on the dielectric heating effect produced in grain, which is a relatively poor conductor of electricity. Since this heating depends upon the electrical properties of the material, there is a possibility of advantageous selective heating in mixtures of different substances. The major advantage of using microwave energy is that no chemical residues are left in the food and hence, there are no adverse effects on human beings (Hurlock *et al.,* 1979). Microwave energy has no adverse effect on the environment. Insects are unlikely to develop resistance to this treatment (Watters, 1976). High frequency radiation may not only kill insects by the dielectric heat induced within them but may also affect the reproduction of survivors (Hamid and Boulanger, 1969). Vadivambal *et al.* (2007) used a pilot-scale industrial microwave system operating at 2.45GHz, to determine the mortality of three common species of stored-grain insects, namely *Tribolium castaneum*, *Cryptolestes ferrugineus* and *Sitophilus granaries* (Vadivambala *et al.,* 2007). Complete kill of adults of all three species and of post-embryonic stages of *T. castaneum* was achieved at 500W with an exposure time of 28 s. Mortality of insects increased with either power or exposure time or both. Germination of wheat kernels was found lower after treatment with microwave energy. Microwave energy treatment does not affect the quality of grain protein, flour protein, flour ash, flour yield and loaf volume of wheat. The difficulty with microwave heating is the large number of factors that affect the microwave heat transfer behaviour such as the thickness, geometry, and the dielectric properties of the food. The heat capacity and dielectric properties change with the moisture content and temperature, which also complicates the microwave drying process (Funebo and Ohlsson, 1998). An inherent problem associated with microwave heating is the non-uniformity in heating caused by an uneven spatial distribution of the electromagnetic field inside the drying cavity. Temperature distribution during microwave heating was studied by many researchers (Fakhouri and Ramaswamy, 1993; Mullin and Bows, 1993; Goksoy *et al.,* 1999 and Manickavasagan *et al.,* 2006).

Gamma irradiation:

Immense applications of gamma radiation in agriculture have been found for reducing post-harvest losses by suppressing sprouting and eradication or control of insect pests, contamination, reduction of food-borne diseases and in extension of shelf life, and for breeding of high-performance well adapted and disease resistant agricultural crop varieties (Andress *et al.,* 1994). Singh and Datta (2010) have recently shown that low dose of gamma irradiation (0.03–0.07kGy)could be poten- tially exploited for improving plant vigor and grain productivity (Singh and Datta, 2010). It is likely that at low dose of gamma irradiation the input use efficiency is favorably affected. Gamma radiation was reported to be a good procedure to improve the nutritional quality of broad bean (Al-Kaisey *et al.*, 2003). Significant positive effect of gamma irradiation at 0.15 kGy was reported on growth and development of okra (Mokobia and Anomohanran, 2005). Singh and Datta (2010), conducted afield experiment to assess the effect of gamma irradiation at 0, 0.01, 0.03, 0.05, 0.07 and 0.1 kGy on standard leaf area, transpiration, stomatal conductance and photosynthetic rate and plant and grain nutritional quality (Singh and Datta, 2010). Gamma irradiation improved plant nutrition but did not improve the nutritional quality of grains particularly relating to micronutrients. Grain carotene which is a precursor for vitamin A, was elevated in irradiated grains. Low grain micronutrients appear to be caused by a limitation in the source to sink nutrient translocation rather than in the nutrient uptake capacity of the plant root.

Detection techniques for stored-product insects in grain:

Acoustical detection:

Acoustical detection methods use insect-feeding sounds to automatically monitor both internal and external grain feeding insects. The insects hidden within kernels of grain can be detected acoustically by amplification and filtering of their movement and feeding sounds. The activity of insects within a grain bulk produces noises in the audible range ofwavelengths, which can be detected by high performance acoustic sensors (Singh and Rai, 1979). A portable probe of 1.4 m length was built up by Fleurat-Lessard *et al.* (1994) with three levelsacoustical sensors coupled to a computer-assisted processing system (Fleurat-Lessard *et al.*, 1994). The recorded sound signals of the major grain insect species were digitized and stored into a reference database. A classification algorithm was developed for the automatic recognition of recorded insect noise signals by their comparison to the specific spectra of the reference database. With such a new PC-assisted insect detectionprobe, the preventive monitoring of live insectpresence is now possible. This preventative approach is in full agreement with the application ofthe HACCP preventative quality assurance systemin grain handling and storing plants (Fleurat-Lessard, 2006). The coupling of acoustic probe to a PC-Assisted decision support system that have been developed recently in major grain-producing countries for insect infestation forecasting orprevention (Flinn and Hagstrum, 1990; Longstaff, 1999 and Mann *et al.*, 1997).

Electronic nose:

Electronic nose is used for the detection of the production of volatiles and odors by microorganisms. It is well known that microorganisms produce a wide range of volatiles,such as sulphur, alcohols, aldehydes, ketones, esters, carboxylic acids, lactones, terpenes, and nitrogen compounds (Pasanen *et al.*, 1996). The volatiles produced occur in foods due to decomposition caused by many microbial contamination, endogenous enzymes or chemical oxidation (Hodgins and Simmonds, 1995) and many factors such as substrate temperature, pH, oxygen concentration, age of culture and microbial species can affect the composition of volatiles. It is well known that flavours are constituted by a large number of components that are perceived as integrated response of the olfactory system to the complex mixture (Craven *et al.*, 1996). The human olfactory system can discriminate aromas without separating mixtures into individual compounds (Aishima, 1991). From this point of view electronic nose parallels the human olfactory system (Bartlett *et al.*, 1997). Olfactory receptors are represented by a group of chemical sensors, which produce a time-dependant electrical signal in response to an odor. Signal processing techniques can be used to reduce any noise and sensor drift. One of the most important uses of the electronic nose regarding the employment of this technology is to obtain an early and rapid detection of fungal and bacterial activity, and thus, it is a useful tool to distinguish between good and poor quality grain (Magan *et al.*, 2003). Paolesse *et al.* (2006) used this technique for an early detection of volatile compounds in infected samples and to discriminate between non-infected and infected samples with two different species of fungi (*Penicillium chrysogenum* and *Fusarium verticillioides*) (Roberto *et al.*, 2006). Zhang and Wang, (2007) used a commercial E-nose (PEN2) comprising 10 metal-oxide semiconductor (MOS) sensors was to generate a typical chemical fingerprint of the volatile compounds present in the samples. They were applied principal-component analysis (PCA)and linear-discriminant analysis (LDA) to the generated patterns to achieve classification into the five groups of differentstorage-age wheats and the 15 groups of different degrees of insect-damaged wheat. The results obtained indicated that the E-nose could discriminate successfully among wheats of different age and with different degrees of insect damage (Zhang and Wang, 2007).

Near-infrared (NIR) spectroscopy:

The NIR spectroscopy developed as a reliable, fast, accurate and economical technique and it can be used for both qualitative and quantitative analysis of grains (Kim *et al.*, 2003). It provides information based on the reflectance properties of different substances present in a product. The NIR is based on the absorption of electromagnetic wavelengths in the range 780–2500 nm. Dowell *et al.* (1999) used the NIR system to detect insects in 1000 kernels per second and find that the NIR method cannot detect low levels of infestations in bulk samples, or discriminate between live and dead insects (Dowell *et al.*, 1999). In contrast, a NIR system is rapid (<1min/sample), does not require sample preparation and could easily be automated for a more sophisticated sampling protocol for large flour bulks.

X-ray imaging:

Soft X-ray imaging recognized as a simple, fast and non-destructive method for detecting hidden insects in grain (Keagyand Schatzki, 1991). Karunakaran *et al.* (2004) used real-time soft X-ray method to detect internal and external insect infestations infestations caused by *Rhyzopertha dominica* in wheat kernels (Fig. 3). They were acquired X-ray images of uninfested and infested wheat kernels using a Lixi Fluoroscope which produces soft X-rays and real time images. Single kernels were placed manually on Saran Wrap on the platform between the X-ray tube and detection system. X-ray images were acquired using 15 kV potential and 65mA current.Images formed on the detection screen were captured by a CCD black and white camera and digitized bya Dazzle digital video creator into 8-bit grayscale images at aresolution of 60 pixels/mm. A personal computer was used for saving the images andperforming the data analysis. (Karunakaran*et al.,* 2004). Narvankar *et al.* (2009) were scanned healthy wheat kernels and kernels infected with the common storage fungi namely *Aspergillus niger*, *A. glaucus* group, and *Penicillium* spp., by using a soft X-ray imaging system (Narvankar *et al.,* 2009).

Fig. 3 : X-ray imaging system

Conclusion:

Damage of stored food grains is very serious problem throughout the world. Due to lack of proper ware housing facilities, stored grain insects largely damage food grains in stores as well as during shipping and transportation. For enhanced protection appropriate methods for storage and disinfecting the food grains are required. Traditional methods usually provide cheap and feasible ways of post-harvest handling of the crops, but they have several limitations. Basically, farmers should be fairly aware about hygienic practices which are essential for successful storing. During storage, some traditional materials are often added to the product, which contribute to the lessening of pests' activity. From the researches, it has been proved that synthetic pesticides are highly toxic to non-target organisms and put adverse impacts on the environment. Therefore, their use should be restricted to minimum. Hence, insect pests have developed resistance to many commercially available synthetic pesticides; thus, new safe alternatives are being searched in form of bio-organic pesticides. The future approach will be an integrated pest management system that consists chemical and nonchemical (biological, physical, hygiene) methods adapted to each specific situation. Among chemicals, new classes of insecticides that are more specific and environmentally acceptable, botanical fumigants and carbon dioxide and repellents, seem to be the best alternatives. However, indigenous storage structures are not suitable for storing grains for very long periods. These provide safe and economical means of grain storage for long durations. There are number of stored grain insect pests that infest food grains in farmer stores and public warehouses and massively surge due to un-controlled environmental conditions and poor ware housing technologyused. However, for suppression of multiplying insect population highly specific and more appropriate modernmethods are to be used. Since January 2005, many uses of methyl bromide have been banned in developed countries because, on penetrating the atmosphere, it is powerful ozone deplete. Hence alternative methods such as ionizing radiation, microwaves, infrared and radiofrequency energy are used successfully for improving the storage period as well as nutritive value of foods. Experiments conducted over the past 50 years have shown that exposures of grain infested by stored-graininsects to radio-frequency and microwave energy can control the insect infestations by dielectric heating of the insects and the grain. Differences have been noted in the susceptibility to control by RF and microwave treatments among different stored-grain insect species and among thedevelopmental stages of those species, depending also on the ages of the insects and on the characteristics of the host medium. In general the immature stages of the insect are less susceptible to control by dielectric heating than the adults of the species, however, there are exceptions. Although microwave heat treatment has many advantages compared to conventional methods, it is still not used widely for commercial purposes, which is due to both technical and cost factors. The quality of microwave-treated products is better or equal to that of conventional drying. However, there are certain drawbacks in microwave heating such as the non-uniform heat distribution and higher equipment costs. Equipment costs can change with time and developing technology. A major improvement in the efficiency of the treatment could change the economics of the microwave process. Thus, microwave heat treatment does appear to have a high potential for the processing of agricultural products in the near future.

Insect populations in grains can be generally monitored by several methods. Acoustical methods can detect only live insects while NIR spectroscopy method can not detect low levels of infestation and cannot differentiate between live and dead insects but very sensitive to moisture content in samples. The electronic nose is a powerful tool able to provide satisfactory indications about the rate of microbial contamination. The soft X-ray method is the only non-destructive and direct method to detect insect infestations both by internal and external grain feeding insects. Thus the soft X-ray is the method which appears to have the greatest potential among the insect detection techniques.

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