Another attribute of great importance for evaluating the quality of soybeans during storage is the acidity index. Soybeans are the main oil source for human consumption in Brazil and there is a maximum acidity limit for the commercialization of the product. In our tests, regardless of the water content of the seeds there is no noticeable influence of the storage temperature on the acidity of the soybean fat. The behavior of this parameter did not follow an expected pattern. According to Christensen and Kaufmann (1969), the vigorous development of fungi and their lipases at a specific moment of the deterioration of the seed increases the free fatty acids value. This explains the drop observed in our graphs, which could be the result of the consumption of portions of the fatty acids by fungi.

Overall, quality, quantity and value attributes of stored soybeans tend to reduce with storage time, being more remarkable at higher temperature and higher moisture content. One can conclude that the temperature of 15ºC, which simulates grain cooling conditions, favors quality maintenance of soybean seeds within a range of water content considered safe for storage. This range should be below 14%, because at or above this level of water content the soybean seeds are considered a moist product and may deteriorate during the storage period, unless the seed mass is stored under cooled conditions.

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Assessment of a mobile solar biomass hybrid dryer for insect disinfestation in dried maize grains

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Abstract

Considerable losses of stored food grains occur through insect infestation in tropical countries because climatic conditions are conducive for insect activity throughout the year. Studies have shown that in order to kill stored grain insects of all life stages temperatures above 50°C are required. However, grain simply laid in the sun or placed in a solar dryer does not reach such high temperatures. This study describes the use of a 1 tonne batch capacity mobile solar biomass hybrid dryer for disinfestation of infested maize and prevention of F1 progeny emergence in stored maize grains. To assess the effect of temperature and exposure period on mortality of maize weevils, infested maize in experimental cages were exposed for 3 and 6 hours of thermal disinfestation treatment in the dryer. Comparing the heat generated in the dryer under hybrid mode operation where additional heat is generated by a biomass furnace in addition to solar, a mean temperature of 67°C was recorded compared to a mean ambient temperature of 36°C. Results showed that there was no significant difference ($p < 0.05$) in mortality of maize weevils during disinfestation treatment for 3 and 6-hour exposure periods. Mortality of 100% was obtained for samples disinfested in the highest tray (level 4) in the dryer. After 30 days of storage of disinfested maize grains, there was no emergence of F1 progeny from the maize grains exposed for 3 and 6 hours. Effect of ambient temperature and open sun exposure periods in the control set-up resulted in low mean percent mortality. Also, samples from the control set-up at both 3 and 6-hour exposure periods showed emergence of F1 progeny after storage. From this study, it can be concluded that an exposure period of 3 hours (or perhaps even less) in the solar biomass hybrid dryer could prevent damage by *Sitophilus zeamais* to stored maize grains after thermal disinfestation at a mean temperature of 67°C.

Keywords: Mobile solar biomass hybrid dryer; disinfestation; maize weevil, mortality,

Introduction

Maize is mostly destroyed by insects such as the maize weevil (MW), *Sitophilus zeamais* and the larger grain borer (LGB), *Prostephanus truncates*. Maize at harvest usually contains too much moisture (20-25%) which is a favourable environment for the growth of fungi and infestation of insects that normally cause grain damage (Folaranmi, 2008).

In Ghana, postharvest losses of maize occur in both the major and minor season which covers the period of April-August or Septmber and Septmber-December, respectively, especially in the middle belts of Ghana (Opit et al., 2014). Quantitatively, losses at harvest may be as high as 20% by weight of grains harvested by an average Ghanaian farmer (Ofosu, 1995 cited in Seidu et al., 2010). The major physiological, physical and environmental causes of postharvest losses are crop perishability; mechanical damage; excessive exposure to high ambient temperature, relative humidity and rain; contamination by spoilage fungi and bacteria; invasion by birds, rodents, insects and other pests; and inappropriate handling, storage and processing techniques (World Bank, 2011).

On the global scale, it is estimated that over two million tonnes of grains are destroyed annually by insects, moulds, rodents, birds and other pests (FAO, 2005). The MW is the most important insect pest of stored maize in tropical and sub-tropical countries (Ukeh, 2008). MW bores a hole through the grain kernel, consumes the endosperm, lays eggs in the holes and multiplies as their generation increases thereby causing vast damage to maize (Parker, 2008). In Ghana, out of an estimated total annual harvest of 250,000-300,000 tonnes of maize, about 20% is lost to MW (Obeng-Ofori and Amiteye, 2005). Therefore, it is important to mitigate these and other postharvest losses to ensure food security in Ghana (Opit et al., 2014). Infestation of maize by insects occurs mostly in the field due to delayed harvesting and also during maize storage. Postharvest activities such as timely harvest, shelling, drying and storage is a major concern because proper handling and storage generates more income to farmers. Grains can be stored for several purposes. Maize can be stored for short term (4-5 months), season-long (6-9 months), and long-term storage for more than 9 months (Mejia, 2008). Since storage is an important aspect of food security in developing countries (Kimenju et al., 2010), it is therefore important to store grains such as maize properly to prevent quality, physical, nutritional and biological losses which may occur.

Several techniques are employed in the storage of grains in developing economies. Some of these techniques include the use of traditional methods, botanical method, biological method, manipulation of drying and storage conditions, and use of synthetic chemicals. Synthetic chemicals are well known for insect pest control due to the important role these chemicals play in reducing storage losses. However, the disadvantages posed by the use of the chemicals such as risk to human health when inhaled and the toxic residues on food products, insect resistance due to its continuous use as well as high cost of these chemicals make them less attractive.

Aside from these synthetic chemicals and traditional methods, the use of non-chemical and low-cost technologies such as tapping the natural source of heat energy from the sun by the use of solar drying systems to heat the air that flows in the dryer, is a very effective, hygienic and efficient method for stored product protection. Solar dryers are specialized devices that control the drying process and protect the agricultural product from being damaged by insects, pests, dust, rain and also from mould infection (Al-Juamily et al., 2007). According to Gatea (2009), the application of solar dryers in developing countries can reduce postharvest losses and significantly contribute to the availability of food.

Exposure to high temperatures to kill insects in stored food grains has long been known by farmers in developing countries where food grains are often laid in the open sun for thermal disinfestation. To achieve high mortality and destroy all life stages of insects, Hansen et al. (2011) reported that use of solar heating in excess of 50ºC to disinfest stored commodities is possible. However, grain simply laid in the sun does not reach such high temperatures.

The present study describes the use of a developed mobile solar biomass hybrid dryer as a potential alterative for the eradication of insects in maize grains. Specifically, mortality of insects as affected by the high temperature and exposure period in the dryer was determined and compared to a control set-up using the open sun energy.

Materials and Methods

Experimental site and unit

The thermal disinfestation experiment was conducted using a developed 1-tonne capacity mobile solar biomass hybrid dryer (Fig. 1) designed and fabricated at the workshop of the Department of Agricultural and Biosystems Engineering, KNUST, Kumasi, Ghana.

Fig. 1 Developed mobile solar biomass hybrid dryer at KNUST, Kumasi, Ghana.

Description and operation of dryer

The mobile solar biomass hybrid dryer (SBHD) is based on a greenhouse structure design that utilizes locally available technology, materials and skills that make on-site construction possible. The dryer has two major parts; the drying compartment with overall dimension of 3 m x 1.8 m x 1.9 m totally enclosed with a 3 mm thick Perspex material. It has four layers of drying shelves (or racks) with a total holding capacity of 1 tonne. As shown in Fig. 2, the drying chamber is coupled to a biomass burner enclosed with a heat exchanger to raise the temperature of air that is blown into the drying chamber with a blower fan solely powered by an installed solar photovoltaic system which includes a back-up battery to store energy for off-peak operation and a DC bulb for night operation. It integrates both solar and biomass energy to generate heat for drying crops or for thermal disinfestation of grain pests such as the MW. In operation, the dryer can rely on direct solar insolation during sunny days where trapped heat from the sun in the chamber is used for drying or disinfestation. Additionally, preheated air from the heat exchanger is forced/pumped into the chamber to affect drying or disinfestation (Fig. 2).

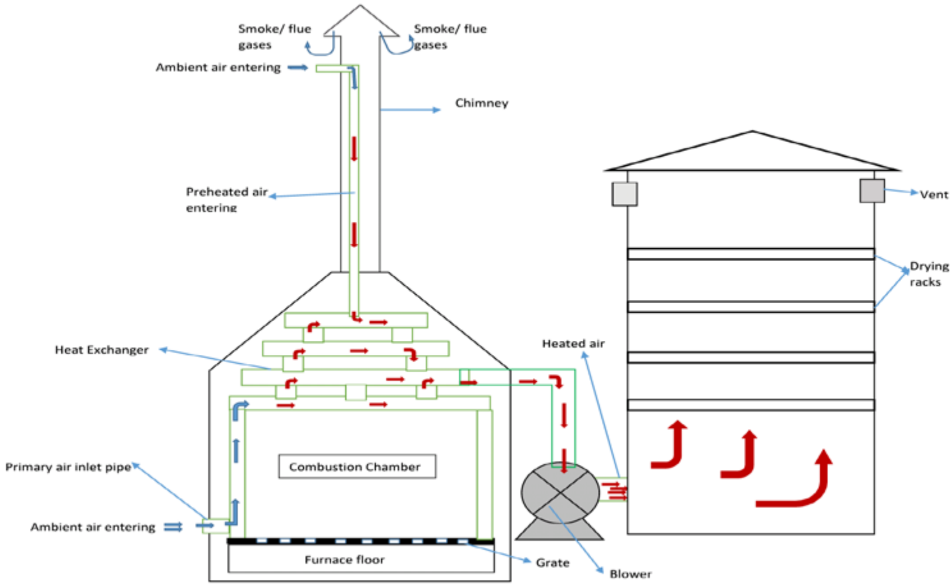

Fig. 2 Schematic view of the solar biomass hybrid dryer showing the air flow movement.

Methods

Culture of maize weevils

About 35 kg shelled maize (*Obatanba* variety) at 14% moisture content was obtained from the Agriculture Research Station at KNUST and used for the experiment. One kg of the dried maize grains was infested with adult *Sitophilus zeamais*. The infested grains were kept at room temperature for 10 days after which the insects were sieved from the grains. The sieved grains were thereafter kept in one litre Kilner jars at room temperature in the Entomology Laboratory of the Faculty of Agriculture at KNUST and cultured until the emergence of adult weevils. Emerged adult weevils served as the stock culture for the experiment.

Experimental set-up

The thermal disinfestation experiment was conducted on different days; 26th January 2017 (10:00 am to 16:00pm) where the heat source was from both solar and biomass energy (hybrid mode operation) and 7th March 2017 (11:00am to 17:00pm) where the heat for disinfestation was generated only from solar energy (insular mode). The experiment was set-up as a factorial experiment arranged in a Randomized Complete Block Design (RCBD). The effect of disinfestation period (3 and 6 hours) and heat source (solar and biomass combined; solar only) on weevil mortality were considered as treatments. Under each heat source application experiment, three replicate samples were set-up at each level in the dryer (four levels/blocks). The control samples were set-up in the open sun during the experiment. Under each experimental trial, 30 aerated cages were stocked with maize samples and the cultured weevils. Each level of the dryer had six cages (three replicates for 3 hours of disinfestation period and the other three replicates for 6 hours). This brought the total cages in the dryer to 24 as shown in Fig. 3. The remaining six cages were set up in the open sun for the same thermal disinfestation period. The cages were fastened together and covered tightly to prevent any possible escape of the artificially introduced maize weevils after they were closed.

Fig. 3 Experimental cages for thermal disinfestation trials.

Disinfestation in solar biomass hybrid dryer

After stocking each cage with 500 g of maize, 20 of the cultured MW of different sexes and age were introduced into each of the 30 mesh-like 'cages' with forceps. The infested maize grains in the aerated cages were later placed on the drying racks/shelves in the dryer for thermal disinfestation at predetermined time intervals of 3 and 6 hours. The temperature profile in the dryer during the experiments under the different heat source applications (hybrid mode and solar only mode) was monitored using Tinytag data loggers (accuracy of ±0.01°C). The loggers were mounted at various levels in the dryer to record temperature conditions in the dryer and in the ambient environment. The loggers logged data at every 10-minute interval during the disinfestation period to account for weather fluctuations during the experiment.

Mortality rate

After the predetermined exposure periods (3 and 6 hours), the insects were separated by sieving the grains. The dead and live insects were counted and recorded. Similarly, the dead and live insects in the control set-up were also assessed. Inspected insects were confirmed dead when there was no response after pricking with the tip of the forceps. Mortality was estimated by counting the number of dead weevils and the mortality rate calculated using Equation 1 provided by Gazzoni (1998):

$$M_r = \frac{dw}{tw} \times 100 \quad \text{................ Eqn. 1}$$

M_r = mortality rate

tw= total number of weevils

dw= number of dead weevils

Emergence of F1 progeny (First Filial generation)

At the end of the thermal disinfestation process, the sieved grains were placed in Kilner jars covered tightly with calico cloths. The containers were kept in the Lab until 30 days after which the number of insects that emerged from each replicate sample were counted after sieving and then recorded. Likewise, the number of insects that emerged from the control were also counted and recorded. This continued daily until there was no emergence of F1 progeny.

Data analysis

Values obtained on weevil mortality were subjected to Analysis of Variance (ANOVA) using Statistix 9. A significance level of 5% was used for all analyses. The Least Significant Difference (LSD) was calculated where a significance was found between treatment means.

Results

Temperature profile in the dryer under hybrid and insular mode compared to ambient temperature

Results of the temperature profile in the dryer relative to the position of the experimental cages during the different heat source applications are shown in Figs. 4 and 5. For the 6 hour disinfestation period, it was observed that temperature conditions in the dryer under both heat source applications varied from the bottom level (L1) to the topmost level (L4) in an increasing trend.

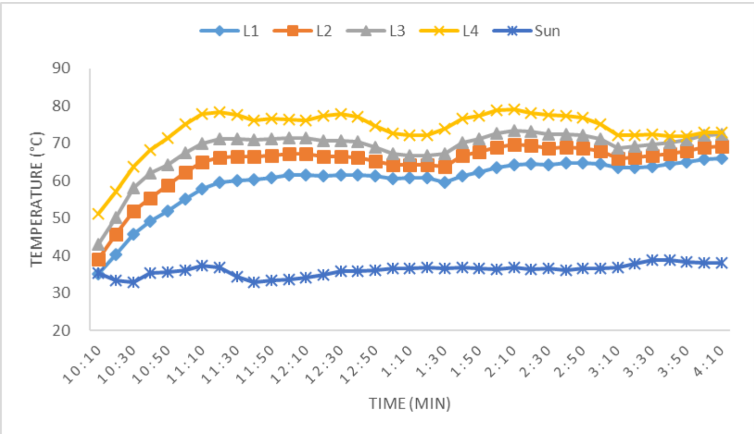

Fig. 4 Temperature variations in the dryer under hybrid mode test

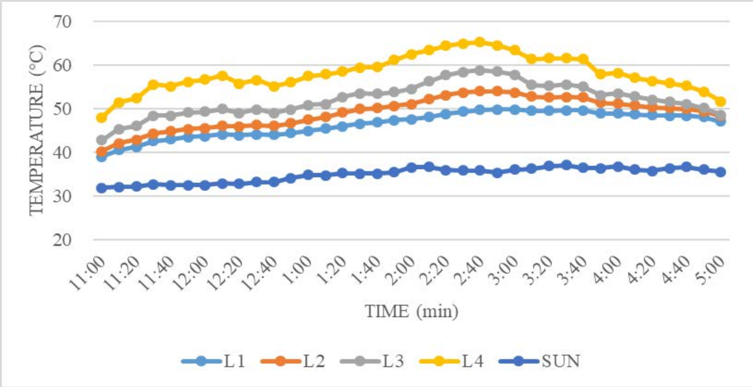

Fig. 5 Temperature variations in the dryer under solar only mode test

As presented in Tab. 1, mean temperature of 67°C was recorded in the dryer during thermal disinfestation using the combined heat source of biomass and solar (hybrid mode) while a mean temperature of 52°C was recorded using solar only as the heat source for disinfestation. Comparatively, the mean temperature inside the dryer was 31°C and 17°C higher than the ambient temperature during disinfestation under the hybrid and solar only modes, respectively.

Tab. 1 Mean temperature for insect disinfestation at 3 and 6 hour exposure periods.

Level	Mean temperatures (°C) at 3 and 6 hours (hybrid mode)		Mean temperatures (°C) at 3 and 6 hours (solar only mode)	
	3 hours	**6 hours**	**3 hours**	**6 hours**
L1	56.1	59.8	44.2	46.5
L2	61.6	64.5	46.5	49.1
L3	66.1	68.4	49.8	52.1
L4	72.4	73.6	56.5	58.1
Overall average in dryer	**64.1**	**66.6**	**49.3**	**51.5**
Sun	35.1	36.1	33.7	34.9

Mortality of adult *Sitophilus zeamais* and F1 progeny

Tab. 2 presents the results of mean mortality of MWduring thermal disinfestation for exposure periods of 3 and 6 hours under the hybrid and solar only mode tests. The mean emergence (F1 progeny) as affected by the temperature and exposure period in the dryer under the two experimental set-ups is also presented (Tab. 2).

Tab. 2 Effect of exposure period and temperature on mortality of *Sitophilus zeamais* and F1 progeny.

Exposure period and heat source	**Mean temperature (°C)**	**Average mortality (%)**	**Mean adult emergence (F1 Progeny)**
3 hours @ Solar + Biomass	64.1	84.9 ab	0
3 hours @ Solar only	49.3	65.4 c	0
6 hours @ Solar + Biomass	66.6	91.6 a	0
6 hours @ Solar only	51.5	78.2 b	0
3 hours @ Control (open sun)	35.1	13.3 d	6
6 hours @ Control (open sun)	34.9	41.2 e	5
LSD (5%)		**8.80**	

Within a column means followed by a different letter show significant difference (p<0.05).

Discussion

Effect of heat source on temperature trend

Temperature conditions in the dryer were significantly higher under the hybrid mode compared to when the heat for disinfestation was solely from the solar energy. However, there was a significant difference ($P < 0.05$) between the temperature conditions in the dryer under both heat source applications compared to ambient air temperatures and direct sun exposure. There was therefore a direct correlation between the energy input for thermal disinfestation and the temperature trend under the different modes of operation of the dryer. The increasing trend in temperature observed under the hybrid mode was due to the high energy input from both heating sources (solar and biomass). This was consistent with the work done by Okoroigwe et al. (2015) who reported that a hybrid heat source has an advantage over sole dependence on biomass or solar. Similar findings were also reported by Bolaji (2005), who designed and constructed a box type indirect solar dryer, where the drying chamber recorded a maximum temperature of 57°C at the time when the ambient temperature was 33.9°C. As clearly presented in Tab. 1, mean temperature conditions recorded in the dryer (hybrid or solar only modes) were above 50°C reported by Fields (1992) who suggested this temperature could cause death of insects within minutes of exposure.

Effect of exposure period and source of heat for disinfestation on mortality of adult *Sitophilus* zeamais and F1 progeny

From the results obtained, the exposure period of infested maize grains in the mobile solar biomass hybrid dryer is vital for thermal disinfestation of MW. Depending on the exposure period and the temperature profile in the dryer, insect infested grains could be controlled for long-term storage. There was significant difference ($p < 0.05$) in mortality of MW with respect to the exposure period and the source of heat used for disinfestation (Tab. 2) as compared to the control experiment.

During disinfestation under the hybrid mode, it was observed that (Tab. 2) mortality of adult weevils after 3 hours (10:10am to 1:10pm) and 6 hours (10:10am to 4:10pm) of exposure time showed no significant differences ($P>0.05$). There was, however, significant difference ($P> 0.05$) in adult weevil mortality during disinfestation relying only on solar energy as the heat source. Moreover, there was no significant difference ($P<0.05$) in MW mortality during thermal disinfestation at exposure periods of 3 hours (hybrid mode) and 6 hours (solar only). The highest mean mortality was achieved at the 6-hour exposure period in the hybrid mode although the results showed that thermal disinfestation under both experimental set-ups (hybrid and solar only modes) recorded a better effect on mortality compared to the control. Recorded mean temperatures were above 50 and 60°C in the dryer under both hybrid and solar only modes, respectively, and below 40°C for the control. Kitch et al. (1992) reported that exposing insects to temperatures above 45°C is known to be lethal to insects with most stored product insect pests known to succumb to death under such conditions. This agrees with Seidu et al. (2010) who reported that mortality of maize weevils exposed to varying temperatures and time in a conventional solar dryer required 120 minutes (2 hours) or more for achieve mortality. This suggests that shorter exposure periods of grains infested with the adult MW is required to achieve high mortality during thermal disinfestation in the hybrid mode while a longer exposure period of no less than 6 hours is required under the solar only mode to achieve the same efficacy.

Results on F1 progeny (Tab. 2) showed that disinfestation under both hybrid and solar only modes over 3 and 6-hour exposure periods was able to prevent the emergence of the MW by destroying all the developmental stages of the weevil during heat treatment in the dryer. However, there was some emergence of F1 progeny in the control under both 3 and 6-hour exposure periods. This is an indication that mean temperatures recorded in the dryer under both hybrid and solar only modes were high enough to kill adult weevils and destroy eggs they might have laid. This was evidence in the non-emergence of F1 progeny after the disinfested grains were stored in the lab for 30 days. However, there was re-emergence of F1 progeny in maize grains treated with the control set-up (open sun disinfestation) where the ambient temperature had little effect on destroying all developmental stages of the MW including any laid eggs. This is corroborated by Agona and Nahdy (1998) who reported that the use of a low-cost solar dryer was effective in ensuring 100% mortality of adult beetles and the non-emergence of adults in solar treated cultures as well as eliminating all developmental stages of *Acanthoscelides obtectus* after exposure for 6 hours above 45°C. Similar trials have also recently been reported by Purdue University, USA researchers in which a similar method was used for killing cowpea weevils (*Callosobruchus maculatus*). They found that ambient temperature had little effect on the temperature developed inside the grain heater, provided that there was sunshine. Their results showed grain temperature of 62°C after 15 minutes of exposure and 100% insect kill after 3 hours. From the assessment of the hybrid dryer for potential use in thermal disinfestation, it was demonstrated that the dryer can be used in preventing damage by *Sitophilus zeamais* to maize grains. All life stages of the MW succumbed to death even at the lowest temperature achieved under the solar only mode within a disinfestation period of 3 hours and above. The successful use of the dryer for thermal disinfestation should be a motivation for farmers who could utilize the developed dryer for both drying their maize grains and controlling insects during storage to minimize postharvest losses and promote food security.

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Green Ecological Grain Storage Technology and Quality Control in China

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Abstract

Green ecological grain storage technologies (GEGSTs) are the means of controlling stored grain quality, and quality changes of stored grain are the basis of GEGSTs control. This paper introduces that GEGSTs are widely used in China, including monitoring and early warning of stored grain pest and mould, pest control by using food-grade materials, controlled atmosphere for pest control, ventilation for lowering and equalizing temperature, low and quasi-low temperature grain storage, treatment of hot spots, etc. And it introduces that grain processing enterprises' and market's request for grain quality, is called "quality control". It also clarifies that stored grain quality control is the purpose, and emphasizes that GEGSTs control is the process, so GEGSTs control should serve for quality control. Therefore, we propose that the technology application and the quality control of grain storage are equally important, and without the quality control, the technology application could be invalid, especially for sensitive areas in grain bulks. In the process of grain storage, special attention should be paid to quality changes in the sensitive areas, like real-time monitoring. Identify and utilize scientific and reasonable technology accordingly, including related technologies and equipment, to improve "overall" quality control level of stored grain bulks, and to gradually standardize them. By means of GEGSTs, positive ecological storage conditions are effectively utilized, which helps us achieve the purposes of safety, no pollution, high quality and nutrition during grain storage.

Key words: Storage Technologies, Grain consumption, Quality Control

Green ecological grain storage technologies (GEGSTs), based on the theory of grain bulk ecology, through the means of green ecological low-carbon, help us achieve the purpose of safety and quality control during grain storage. Grain storage technology control is a process, and grain storage quality control is the purpose, so grain storage technology control should serve for stored grain quality control. After harvest of grain, quality control in grain circulation involves three aspects, which are grain quality during consumption, warehousing and storage. Among them, stored grain quality is related to the warehousing quality and grain consumption quality, taking into account the two links of grain production and grain consumption. It is the key to do a good job in the convergence and coordination of these three aspects, to improve the technical level of grain storage management.

1. Green ecological grain storage technologies

GEGSTs are widely used in China, including pest control by using food-grade materials, ventilation for lowering and equalizing temperature, controlled atmosphere for pest control, low and quasi-low temperature grain storage, monitoring and early warning of stored grain pests and moulds, treatment of hot spots etc.

With the development of insect pheromones and different wavelength spectra to attract stored-grain pests, the density and insect situation of stored-grain pests in a granary could be monitored by using new trapping technology. Combined with the detection of grain condition, the population dynamics of stored-grain pests under different ecological conditions could be predicted, and thus the decision-making control technology was put forward. Integrated with grain storage information technology and other high-tech, a new core technology of comprehensive control of stored grain pests is formed.

Pest control technology by using food-grade materials is an upgrade of traditional inert-powder pest control technology with plant ash, diatomite and others. Insecticidal mechanisms of food-grade materials fall into the internode membrane of the insect body, which would lead to wear the