LITERATURE REVIEW

***Platydema waterhousei* Gelbien**

Platydema waterhousei Gelbien (Coleoptera: Tenebrionidae) is one of an important pest of Ling–Zhi mushroom. Its infestation occurred both preharvest and postharvest. Developmental periods of *P. waterhousei* were reported by Visarathanonth *et al.* (2000). The average egg period was 6.20±0.41 days. Larvae possessed 9 to 10 instars. Each larval stage averaged 3.04±0.61, 3.32±0.75, 4.00±1.04, 3.64±1.00, 4.16±1.55, 4.64±1.35, 4.80±1.35, 4.59±0.91, 4.64±1.21 and 3.00±0 days, respectively. All instars secreted fibrous material from the anus. The prepupae span the fibers into a tight cocoon and pupated inside the fibrous cocoon. The pupal stage averaged 4.24±1.44 days. Adult longevity averaged 224±43.9 days in male and 204.88±44.86 days in female. Sex ratio was 1: 0.8, male: female.

***Ganoderma lucidum* (Fr.) Karsten**

Ganoderma lucidum (Fr.) Karsten have various names such as Ling-Zhi, ling chi and Reishi. It is a saprophytic fungus on decaying hardwood logs and on stumps. It is commonly found in warm climates. *Ganoderma lucidum* is in the class Basidiomycetes and family Ganodermataceae. Its distinguishing characteristic is kidney like shape and red varnished surface (Jong and Birmingham, 1992).

Ganoderma lucidum is an interesting medicinal fungus because it has been represented as the herbal remedy for maladies such as anticancer and anti-inflammation (Zhou and Gao, 2002), anti-HIV (El-Mekkawy *et al*., 1998), heart damage protection (Wong *et al.,* 2004), hepatitic and renal protection (Ying *et al.,* 2001). Recently, there have been a number of scientific papers published with experiments attempting to quantify the effect of *G. lucidum*. The fungal extract has been shown to act on immune system cells, to work against herpes virus and antibacterial, to lower cholesterol and stop cell proliferation (Jones, 2000; Min *et al*., 2002).

Two primary compounds identified from *G. lucidum* included polysaccharides and triterpenes. Polysaccharides occurred in the form of beta -D-glucans bound to amino acids. These agents possessed immune system and anticancer effects which induced apoptosis in leukemic cells and cell differentiation and inhibited angiogenesis. Triterpene compounds, ganoderic acids, could reduce high blood pressure and platelet aggregation, which may help to decrease risk of cardiovascular disease (Davidson, 2001; James, 2002; Zhou and Gao, 2002; Gao *et al*., 2004b; Jiang *et al*., 2004; Liu and Zhang, 2005).

Control of Stored Product Insects by Modified Atmospheres

Causes of Egg, Larval, Pupal, and Adult Mortality after Exposure to Modified Atmospheres

Aliniazee (1971b) studied the egg hatched of *Tribolium confusum* and *Tribolium castaneum* in different carbon dioxide concentrations. They found that the toxicity of high CO_2 may be owing to its hindering the normal metabolic growth process of egg or the analgesic effect of gas on embryo nervous system.

Mbata *et al*. (2000b) indicated that a high CO_2 atmosphere reduced nicotinamide adenine dinucleotide phosphate (NADPH) formation, decelerated the rate of adenosine triphosphate (ATP) mediated reactions and inactivated the regeneration of acetylcholine from choline. Hypercarbic atmosphere could be a factor causing early death in pupae and late pharate adults because high CO_2 levels led to high accumulation of metabolites that produced acidity in the haemolymph of pupae.

Ofuya and Reichmuth (2002b) reported that when exposed *T. castaneum* adults to high CO_2, their mortality caused by desiccation and deficiency of triglyceride energy reserves rather than by the anesthetic effect or the aggregation of toxic end products. Similar results were confirmed by Leelaja *et al*. (2006). In addition, they reported that CO_2 above 35% levels caused insect death by acidification at the cellular level.

Zhou *et al*. (2000a) studied metabolic response of *Platynota stultana* pupae to controlled atmospheres. They found that the mortality of *P. stultana* pupae, under elevated CO_2 atmospheres, was related to metabolic arrest and anaerobic metabolism. Moreover, concentration of 40% CO_2 caused *P. stultana* pupae's body fluid to leak out, suggesting that the insect membrane systems were affected because CO_2 could enlarge intracellular Ca^+ by lowering pH (Zhou *et al*., 2000c). Therefore, increasing CO_2 levels caused intracellular Ca^+ to raise more and quicker, leading to cell damage or death (Zhou *et al*., 2000d).

Other effects of modified atmospheres on treated insects were also reported. For example pupae and emerged adults of *T. confusum* and *T. castaneum* exhibited morphological abnormalities when larvae and pupae were exposed to 100%CO_2, respectively (Aliniazee, 1971a). In addition, exposure to CO_2 could prevent the full distension of wings in the newly eclosed *Plodia interpunctella* male (Lum, 1974).

Callosobruchus maculatus lifetime fecundity was lessened after exposure to 100% CO_2 atmosphere for 8 min (Dawson, 1995). Similarly, after exposure to high CO_2, the codling moth, *Cydia pomonella* (L.) oviposition was reduced (White *et al.,* 1970), and the fecundity of *Drosophila melanogaster* was decreased (Perron *et al*., 1972).

Moreover, growth of the German cockroach, *Blattella germanica* (L.) was delayed when exposed to 5% CO_2 for 3 min (Brooks, 1957). Most *T. confusum* and *T. castaneum* had extended larval periods after exposing to 100% CO_2 (Aliniazee, 1971a).

Some Factors Affecting Efficacy of Modified Atmospheres

Factors that affected efficacy of modified atmospheres include concentration of atmospheric compositions (CO_2, O_2 and N_2), relative humidity (rh), temperature, exposure time, insect species and strains, developmental stages and level of infestation (Soderstrom *et al.,* 1992; Ofuya and Reichmuth, 2002a; Gunasekaran and Rajendran, 2005)

Concentration of Atmospheric Compositions

Lindgren and Vincent (1970) studied mortality of *Sitophilus granarius* and *Sitophilus oryzae* caused by modified atmospheres. They found that concentrations of 90-40% CO_2 in air were more toxic to *S. oryzae* adults than 100% CO_2. Similarly, *S. granarius* adults were more sensitive to 90-60% CO_2 than to 100%CO_2. Mbata and Reichmuth (1996) studied mortality of *Callosobruchus subinnotatus* when exposed to four modified atmospheres containing high levels of CO_2 and various quantities of O_2 (0, 2, 3.7, 5.1% O_2). The 100% CO_2 was most toxic to eggs, larvae and pupae. Otherwise, the atmospheres composed of 2.0 or 3.7% O_2 enhanced the mortality of adults.

Relative Humidity

Jay *et al.* (1971) investigated importance of relative humidity on mortality of adults of *T. confusum*, *T. castaneum* and *Oryzeaphilus surinamensis* exposed to either binary or ternary atmospheric conditions. The binary mixtures were composed of carbon dioxide and nitrogen. The ternary mixtures consisted of oxygen, carbon dioxide and nitrogen. They found that insect mortality increased with lessened relative humidity when the insects were exposed, for a certain period of time, to either the binary or the ternary mixtures.

Ofuya and Reichmuth (2002a) studied effect of relative humidity on the susceptibility of *C. maculatus* exposed to 70% CO_2 in air or 1% O_2 in N_2 at 25$\pm$2 ^oC. The mortality of eggs and adults was greater at 10$\pm$3% and 34$\pm$2% than at 70$\pm$2% and 90$\pm$3% rh. On the contrary, lethality of larvae and pupae, exposed to modified atmospheres, was not influenced by the relative humidity. In addition, the development time was prolonged for adults emerging from eggs exposed to these atmospheres for 12 hr at 10$\pm$3% and 34$\pm$2% rh.

Temperature

Temperatures were also important factors for modified atmospheres. Soderstrom *et al*. (1992) studied mortality of *T. castaneum* larvae exposed to elevated carbon dioxide or oxygen deficient atmospheres at $\geq$38^oC. Their results indicated that under higher concentrations of CO_2, increasing temperatures could reduce treatment times.

In addition, Navarro *et al*. (2002) studied the effectiveness of controlling *Trogoderma granarium* larvae, and all stages of *Ephestia cautella* and *O. surinamensis* by vacuum or carbon dioxide in combination with temperatures ranging from 35 to 45^oC. They found that insect mortality increased with increasing temperatures. Similar results had been reported by Harein and Press (1968). They exposed *T. castaneum* adults and larvae, and *P. interpunctella* larvae to binary (nitrogen, oxygen) and ternary (nitrogen, oxygen and carbon dioxide) mixtures of gases. Mortality of insects increased by lengthening exposure times, increasing the exposure temperatures, and enhancing CO_2 levels.

Exposure Period

Rameshbabu *et al.* (1991) exposed *Cryptolestes ferrugineus* adults and eggs to three combinations of CO_2, O_2 and balance of N_2 in the range of 0-100% for each gas. The maximal mortality of adults (99%) and eggs (85%) was achieved at high CO_2 (88-97%), low O_2 (0-0.5%), high temperature (19.5-20.5^oC) and low relative humidity

(60.0-60.3%) at exposure times of 96 hr. In addition, Harein and Press (1968) studied mortality of *T. castaneum* adults and larvae, and *P. interpunctella* larvae exposed for 7 and 14 days to mixture of atmospheric gases (CO_2, O_2 and N_2). They found that the percentage mortality, of both species, after 14-day exposure was higher than after 7-day exposure.

Insect Species

The efficacy of modified atmospheres also depended on insect species. Adults of *S. granarius, T. castaneum, O. surinamensis, C. ferrugineus* and *Rhyzopertha dominica* were exposed to atmospheres containing 0.5-2.6%O_2 and 10-30% CO_2 with a balance of N_2 at 20 ^oC and 70% rh. At 2.6 %O_2 with 20% CO_2 in N_2 *C. ferrugineus* were more tolerant to CO_2 than the other insect tested. At 0.5%O_2 with 0-20% CO_2 in N_2 *S. granarius* were the most tolerant species, requiring 8-10 day for absolute mortality (Krishnamurthy *et al*., 1986). Moreover, Aliniazee (1971a) found that 95% mortality of *T. confusum* adults was achieved by exposing them to 45%CO_2: 55% air mixture for 271 hr, to 62%CO_2: 38% air mixture for 58 hr, and to 80 %CO_2: 20% air mixture for 47.5 hr whereas that of *T. castaneum* adults took 192, 60 and 44 hr, respectively.

In 2002, Navarro *et al.* investigated complete mortality of *E. cautella* and *O. surinamensis* when exposed to 90%CO_2 in air at 40^oC. The absolute mortality of eggs, larvae, pupae, and adults of *E. cautella* wanted 5, 6, 4, and 2 hr, respectively whereas that of *O. surinamensis* needed 6, 2, 5, and 3 hr, respectively.

Insect Strain

The effectiveness of modified atmospheres also relied on insect strain. Donahaye *et al*. (1992) exposed selected and unselected strains of *T. castaneum* to 65%CO_2: 20%O_2: 15%N_2 atmospheres. The selected strain was screened for resistance in the adult stage to a high-CO_2-content atmosphere. They found that times required for the 99% mortality of the selected strain of eggs, larvae, and adults were higher than that of the unselected strain. However, the 99% mortality of the unselected strain pupae took longer time than that of the selected strain. Childs and Overby (1983) studied mortality of *L. serricorne* (Fr.) in high-carbon dioxide atmospheres. They found that a strain of *L. serricorne* reared on tobacco was more tolerated to CO_2 than a strain reared on wheat flour.

Developmental Stage

The toxicity of modified atmospheres varied in relation to developmental stage. Aliniazee (1971a) exposed all stages of *T. castaneum* and *T. confusum* to 100%CO_2. He found that pupae were most tolerant followed by eggs, larvae and adults.

Storey (1975) studied the mortality of *S. oryzae* and *S. granarius* in modified atmospheres with low oxygen, <1%O_2, 8.5-11.5%CO_2 and the balance with N_2 at 27 ^{o}C. He indicated that earlier and later stages were more susceptible than the middle stages. In the tests with the *S. oryzae* at 27 ^{o}C, eggs, 1st-instar and pre-emerged adults were highly sensitive, but 4th-instar through young pupae were most tolerant. The results with the *S. granarius* in the tests at 27 ^{o}C were similar to those acquired with the *S. oryzae* at 27 ^{o}C. However, the egg, pre-adult and adult stages of *S. granarius* took longer exposure times to achieved 95% mortality than was required by the same stages of the *S. oryzae*. The times required for 95% lethality for *S. granarius* larvae increased as the developmental process progressed. Conversely, the time required for 95% mortality for the pupae decreased with increasing age.

Mbata *et al.* (1996) investigated mortality of all stages of *C. subinnotatus* when exposed to 100% CO_2 atmospheres. They reported that eggs were most sensitive when exposed to 100%CO_2 followed by larvae and pupae.

Annis and Morton (1997) exposed *S. oryzae* to 15-100%CO_2 in air at 25 ^{o}C and 60%rh. At 65% CO_2 concentrations pupae and adults were the most tolerant and most susceptible stages, respectively. At 20% CO_2 concentrations eggs were the most sensitive stage.

Mbata *et al.* (2000a) investigated mortality of pupae, early pharate and late pharate adults of *C. subinnotatus* when exposed to hypercarbia (60%CO_2: 32%N_2: 8%O_2 and 99%CO_2: 0%N_2: 1%O_2) and hyperxia (0%CO_2: 98%N_2: 2%O_2 and 0%CO_2: 99%N_2: 1%O_2) at 30 ^{o}C and 76%rh. They found that late pharate adults were more susceptible than the pupae or early pharate adults.

Gunasekaran and Rajendran (2005) studied mortality effect of CO_2 against *Stegobium paniceum* and *L. serricorne*. In both species, the pupal stage was most tolerant followed by larval, egg and adult stages.

Level of infestation

Efficacy of modified atmospheres was also dependent on the level of seed infestation. Ofuya and Reichmuth (1994) studied mortality of *C. maculatus* larvae and pupae at the two levels of seed infestation. The high level of seed infestation possessed 10-20 larvae or pupae per seed. The low level of infestation had 1-2 larvae or pupae per seed. They found that mortality of larvae and pupae was higher in seeds with low infestation than in seeds with high infestation. Seeds infested with insects may influence the absorption pattern of the gases through the seeds and flushing with CO_2 or N_2 may more readily remove air pocket in seeds with a few insects than in seeds with ten to twelve insects.