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Survey and Analysis of Economic Thresholds for Insect Pest Control in Grain Storage in the Fujian Area of China

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Abstract: With reference to flour beetles and boring beetles, grain type, and fumigation temperatures, and so on, the basic relationship between stored grain insect control and economic thresholds were investigated by analyzing benefit and cost of the control practices in seven depots of State Grain Reserves (159 warehouses holding 891,700 t of grain) in Fujian province. The following main conclusions could be drawn. First, the economic threshold for boring beetles in stored grain was lower than that for flour beetles, and the reduced economic loss was more than control cost for boring beetles at the same condition. Second, the economic threshold for wheat and maize was lower than that for paddy rice, and treatment cost for controlling the same insects in wheat and maize was lower than the reduced economic loss at the same condition. Third, the economic threshold was lower when the grain temperature above 20℃, and higher when the grain temperature was below 15℃.

Key words: Fujian province, insect control, economic threshold

Introduction

The optimal environmental conditions for common stored grain insects are over 20℃ and 70% relative humidity. The high temperature and humidity climate of Fujian province is therefore very favorable for such insects. About 3.5 million t of stored grain requires insect control every year in Fujian. For insect control, factors such as insect species, grain type, grain temperature are relevant to economic thresholds. Most grain storage units implement phosphine fumigation when finding insects, without considering economic thresholds. This results in 3 – 4 fumigations on average for each batch of grain in storage, with significant social, economic and environmental impacts. These include increased insect resistance and associated difficulty in controlling insects, accelerated grain spoilage and contamination, shortened storage time, and decreased selling price. Therefore, direct and indirect economic value is very high when considering if insect control should be taken in Fujian province. Providing a relationship between insect control and economic threshold in a high temperature and humidity area based on insect species, grain type, control opportunity, and so on, to guide insect control practices in grass – root depots, will have great social, economic and environmental benefits.

Survey of Integrated Stored Grain Insect Pest Control in Fujian

Climatic Characteristics and Common Stored Grain Insects

Fujian province is located on the southeast coast of China. Most of Fujian experiences high temperature and humidity typical of sub-tropical coastal China, with warm winters, hot summers, and high rainfall. Average annual temperature is 17 – 21℃, with temperatures sometimes exceeding 40℃ for extended periods, and average annual relative humidity is 76 – 84%, so conditions are favorable for insect population growth. It was found that the frequency occurrence of stored grain insects, was over 50% by investigating stored grain insects species, damage in Xiamen, Sanming, Shaowu, Fuzhou, Putian, Zhangzhou, Quanzhou, from April to May in 2004[1], 2005, and 2006, and from June to September, 2007. Pest species included *Rhyzopertha dominica* (Fabricius), *Sitophilus zeamais* (Motschulsky), *Sitophilus oryzae* (Linnaeus), *Alphitobius diaperinus* Panzer, *Sitotroga cerealella* Oliver, *Tenebroides mauritanicus* (Linnaeus), *Tribolium castaneum* (Herbst), *Tribolium confusum* Duval and *Cryptolestes ferrugineus* (Stephens). of these species, *R. dominica*, *S. zeamais*, *S*, *cerealella*, *T. confusum* and *C. ferrugineus* were the most common, which greatly increased insect control difficulty and cost of depots of State Grain Reserves in this region of high temperature and humidity.

Investigation of Storage Equipment in Depots

1. *Fujian Branch of China Grain Reserves Corporation*, *Fuzhou* 350001
2. *Xiamen Depot State Grain Reserves*, *Xiamen* 361012
3. *Shaowu Depot State Grain Reserves*, *Xiamen* 354000

Depots in Fujian province are distributed very widely, and the storage equipment in the various warehouse differ greatly from each other. Most of the large warehouses, squat silos and other silos were built after 1998, and account for 28.2% of storages in Fujian. They have high levels of airtightness and heat insulation, and they are equipped with mechanical ventilation, recirculation fumigation, electronic temperature monitoring system, etc., which offered excellent hardware equipments for insect control. Most of warehouses, horizontal warehouse of Soviet, arch plate depots were built after the 1980s, accounting for 71.8% of storages in Fujian. They have low standards of airtightness and heat insulation, and most do not have mechanical ventilation, recirculation fumigation, or an electronic temperature monitoring system. Thus insect control is difficult and very costly.

The Present Insect Control Condition of Grass-root Depots

In the early stages of the establishment of the state grain reserves management system, the basic requirement of state and grain administration departments for grass-root depots was for "Four No's depots", i.e. no insects, no mould, no rodents or birds, and no accidents. In order to realize the requirement of no insects, most of grass-root depots took a "saturation management" strategy, i.e. immediately implementing fumigation once insects appeared. After the establishment of the Fujian vertical administration system of State Grain Reserves, insect control strategy was adjusted to an integrated pest management (IPM) strategy. Provided no influencing on safety grain storage and grain quality, integrated insect management (IPM) was positively popularized in Fujian. The amount of green grain storage without fumigation increased from 0% in 2003 to over 20% in 2008. Some warehouses achieved excellent results, with only one fumigation in 2 or even 3 years. Thus, over 20% stored grain in depots directly under State Grain Reserves are not fumigated.

Discussion on Application of Economic Threshold theory during Insect Control

Primary Principle of Economic Threshold

The primary principle of economic threshold of insect control is that control cost should be less than or equal to reduced economic loss. Sheng Cheng-fa [2] put forward the newest definition by integrating different definitions expounded by entomologists and agro-economists based on different understanding, i.e. the control measures should be taken when insect density reaches a definite density, otherwise, the insect will bring an expected loss which equals the expected cost of the control measures. Thus, economic threshold can be understood as degree tolerance before insect control. The higher the economic threshold, the higher degree of tolerance to the insect. Conversely, the lower the economic threshold, the lower degree of tolerance to the insect.

The impact factors of economic threshold are various, including the relationship between environmental factors and insect survival, development and reproduction, type and degree of damage caused by different insects, population density and injury level, suitable control opportunities, the availability and cost of control measures, selling value of the grain, and so on. The general model of economic threshold is the following equation [3].

$$ET = CF/EYHDS$$

Where ET is economic threshold, C is control cost, F is social adjustment factor, E is control effect, Y is yield when no insects, H is production price, D is yield loss damaged by per unit insect, and S is insect population natural livability. For insect control, Y should be grain natural storage quantity. Therefore, economic threshold is not invariable, and it will change with environmental conditions, insect species and its damage potential, production value, etc. The essence of economic threshold put forward by Sheng Cheng-fa [2] is a multidimensional, dynamic, random economic-ecology parameter, its theory value can not be known. The economic threshold should be estimated in relation to relevant major factors in storage practice.

The Relationship Between Stored Grain Insect Control and Economic Threshold in Fujian

The Relationship Between Different Kinds of Stored Grain Insect and Economic Threshold

The damage of boring insects in stored grain

In practice, the major stored grain boring insects are *R. dominica*, *S. zeamais*, *S. cerealella*, and their frequency of occurrence was about 85%. By trace-back investigation of 18 warehouses with the records of no fumigation and no stored grain at present time, it was found that boring insects occurred and were controlled with IPM measures in 13 warehouses, and the cost of

control was 0.10 – 0.15 yuan/t. As a result of taking timely and suitable control measures, the warehouses implemented only one time during 3 years storage, 2 times for 4 years storage, not only saving control cost 0.55 – 1.15 yuan/t, but also delaying grain spoilage and improving grain quality. The grain selling price was 20 – 40 yuan/t higher than that of grain in other warehouses not being timely controlled at the same condition.

By analyzing fumigation data in past years in Fujian depots directly under central grain reserves, it was found that if control measures were undertaken when average grain temperature is over 20℃ or over 25℃ in sites of insect occurrence in the grain mass, or the density of boring insects (e. g. *R. dominica* and *S. zeamais*) is over 5 – 10/kg, then control was relatively good and control cost relatively low.

The damage of flour insects in stored grain flour

The most common major flour insects are *C. ferrugineus* and *T. confusum*, and their frequency of occurrence is about 80%. By investigating 18 warehouses with the records of no fumigation and no stored grain at present time, it was found that fumigation was not immediately taken when flour insects occurred in five warehouses. They implemented IPM measures, i. e. taking some low cost control measures, such as trapping, and mechanical and physical treatment. The cost of control was 0.05 – 0.10 yuan/t. As a result of taking timely and suitable control measures, these warehouses implemented only one time for 3 years storage period, two times for 4 years storage period, not only saving control cost about 1.5 yuan/t, but also delaying grain spoilage. Their grain selling price was 20 – 30 yuan/t higher than that of grain in other warehouses not being timely controlled at the same condition.

It should comprehensively consider control cost when flour insects occurring. It is not necessary take chemical control, and IPM measures should be taken when no or a few boring insects occurring, and local *C. ferrugineus* and *T. confusum* density below 15 – 25/kg.

The Relationship between Stored Grain Kinds and Economic Threshold

By investigating the insect resistance in the three major grains (wheat, corn and paddy rice), it was found that the insect resistance in wheat and corn was comparatively weak, being susceptible to infestation by stored grain insects. The unsound kernels universally increased in infected wheat and corn, average increasing by about 1%, and more infected kernels, accordingly more kernels, by investigating the insect resistance of wheat stored in eight warehouses holding 20 000 t for two years in Xiamen grain purchasing and storage company, and the insect resistance of corn stored in eight warehouses holding 47 500 t for one year in Fuzhou, Putian and Xiamen depots directly under central grain reserves. It is obvious that insects give birth to more negative effect on wheat and corn quality, and less effect on paddy rice quality at the same condition.

Therefore, insects will bring more production loss of wheat and corn at favourable environmental condition. Meanwhile, since the absorption capability of paddy rice is stronger than that of wheat and corn, the dosage in paddy rice is often higher than that in wheat and corn during fumigation. According to practical experiences of depots directly under central grain reserves in recent several years, the dosage per tonne of paddy rice is often about 1.2 g higher than that of wheat and corn during fumigation under the same conditions, and its control cost is higher than that of wheat and corn. Therefore, IPM measures should be first taken when insects occurring in paddy rice, trying to reduce chemical fumigation.

The Relationship between Stored Grain Temperature and Economic Threshold

By tracing investigation on insect occurring and developing condition in 54 warehouses fumigated in the same year, it was found that the grain temperature in 42 warehouses was over 20℃, accounting for 78%, and the grain temperature in 12 warehouses was 20 – 15℃ during fumigation, accounting for 22% among the warehouses keeping no insect occurring for over 12 months next year after fumigation. The grain temperature in 18 warehouses was over 20℃, accounting for 78%, and the grain temperature in 5 warehouses was 20 – 15℃ during fumigation, accounting for 22% among the 23 warehouses keeping no insect occurring for over 18 months next year after fumigation. According to general model of economic threshold ET = CF/EYHDS, Svalue (insect population natural livability) increased, Evalue (control effect) also increased, and then ET value decreased.

Therefore, the insect control economic threshold is comparatively small when the grain temperature is over 20℃. Because the growth, development and reproduction of most of stored grain insects are inhibited when the grain tem-

perature is below 15℃, insect population natural livability is very low, control effect is bad, insect resistance is easily be induced, economic threshold also accordingly increases, thus trying to avoiding chemical fumigation.

The Relationship between Insect Control Measures and Economic Threshold

When insect density reaches the unendurable level in practice, phosphine fumigation is the most economic, convenient and effective measure. One time fumigation cost was about 0.6 yuan/t in depots directly under central grain reserves in Fujian based on investigation, including PH_3 quantity average 0.2 yuan/t, fumigation nutrition subsidization about average 0.25 yuan/t, labour wage, electricity expenses, and depreciation expenses of fumigation machine, plastic film and other fixed assets about average 0.15 yuan/t. But the fatty acid value of grain after fumigation will increase 2% – 3% in high temperature seasons, which accelerates grain spoilage, shortens storage time, increases grain alternation times with increasing cost about 50 yuan/t. In addition, the grain color and odor also is changed after fumigation, directly influencing grain selling price. The selling price of grain after several times fumigation is about 20 – 40 yuan/t lower than that of grain with no fumigation.

Discussion and Conclusion

Though the direct cost of chemical fumigation is comparatively small, it brought indirect huge economic loss. Hence, the control principle "prevent first, integrated control" should be carried out during grain storage, taking endurance philosophy to manage insects. Positively take integrated measures of non-chemical control to inhibit insects occurring, try to reduce chemical fumigation, especially avoid chemical fumigation in whole warehouse.

The damage of boring insects is more than that of flour insects. According to general model of economic threshold ET = CF/EYHDS, D value, i. e. yield loss damaged by per unit boring insects is more than that of per unit flour insects. Furthermore, for the most common flour insect, *C. ferrugineus*, due to having the highest resistance, control cost is higher than that of most of boring insects in Fujian area. Therefore, if the other condition is invariable, the economic threshold of boring insects is lower than that of flour insects in Fujian area, i. e. boring insects should be taken chemical fumigation when its density is very low, and flour insects may be taken chemical fumigation when its density is very high. However, the relationship is not absolute. Because of different insect resistance, the control cost is a little difference.

The economic threshold of wheat and corn is lower than that of paddy rice, i. e. for wheat and corn, control measures should be taken when insect density is very low, and for paddy rice, control measures may be taken when insect density is very high. But insect infection probability is very different even at the same condition for the same stored grain species. Dry, clean and sound grain kernel is hard to be infected, contrarily, it is easy to be infected.

The economic threshold of insect control is very low when the grain temperature is over 20℃. When the grain temperature is below 15℃ which can inhibit most of stored grain insects growth, development and reproduction, insect population natural livability is very low, control effect is relatively bad, insect resistance is easy to be induced, and the economic threshold is accordingly increasing. Thus, it need try to take integrated control measures and reduce chemical fumigation.

All in all, in order to reduce the insect control economic threshold, various factors should be integratively considered to select suitable control opportunity and measures. The following are the detailed suggestions:

1 Fumigation should be timely taken when average grain temperature is over 20℃ or insects occurring sites temperature is over 25℃ in wheat and corn warehouses, and when *R. dominica*, *S. zeamais*, and other boring insect population density reaches over 5 – 10/kg more than 3 parts of the grain mass, here control cost very low.

2 Temperature should be first decreased and fumigation done when average grain temperature is over 30℃ for corn and paddy rice, and over 35℃ for wheat. Not doing this will result in accelerated grain spoilage, a shorter storage period and lower selling price.

3 The effectiveness of fumigation is very good when average grain temperature is 20 – 30℃. When average grain temperature is below 15℃, chemical fumigation should be avoided and non-chemical control measures should be taken, or else insect resistance may be induced.

4 Controlled temperature grain storage, behaviour control, physical and mechanical control, biological control, local fumigation control, and other techniques should be positively taken to inhibit insect development, to reduce fumiga-

tion and reduce insect control economic threshold, when no insect or less insects existing, and when *C. ferrugineus* , *T. confusum* and other flour insects density is below 15 – 25/kg.

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