INTEGRATED APPROACH TO THE USE OF CONTROLLED ATMOSPHERES FOR INSECT CONTROL IN GRAIN STORAGE*

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INTRODUCTION

Significant progress has been made in recent years in using modified atmospheric gas concentrations for the control of stored product insects (Banks, 1979; Navarro et al., 1979; Shejbal, 1979). Contributions on this subject have shown the feasibility of using low oxygen concentrations in nitrogen atmospheres, high carbon dioxide concentrations or a mixture of these gases as efficient non-chemical control methods for the prevention of insect damage (Jay and Pearman, 1973; Shejbal et al, 1973; Navarro et al., 1979). However, it should be kept in mind that the atmospheric gas composition is only one of the factors acting on insects breeding in the grain bulk ecosystem (Banks and Annis, 1977). Other environmental factors affecting the survival of insects found in bulk-stored grain are temperature and relative humidity (Navarro, 1978; Storey, 1975). Therefore, the efficient use of controlled atmosphere storage should require the careful consideration of data concerning these two factors, which in some cases could be modified to increase the efficacy of this control method.

In this paper the effect of temperature and relative humidity on the effectiveness of atmospheric gas mixtures as an integrated approach to the control of stored grain pests, is described and discussed.

INSECTICIDAL EFFECT OF MODIFIED ATMOSPHERES

The effect of low O_2 or high CO_2 concentrations on insect mortality was demonstrated many years ago (Bailey, 1955; Bailey, 1965). A limit of about 2% O_2 has been indicated (Banks, 1979) for the mortality of stored product insects so far tested. These findings provided the basis of the revived ancient method of hermetic storage (Bailey and Banks, 1974). However, the concentrations of low O_2 or high CO_2 needed for the control of different stored product insect species

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differ widely (Harein and Press, 1968; Marzke et al., 1970).

Direct comparison of the many results given by numerous researchers in this field is difficult, since the insect mortalities obtained in various gas compositions at different temperature and humidity levels are so diverse (Bailey and Banks, 1974; Harein and Press, 1968). The effect of modified atmospheres on immature stages varies also, and this has been the subject of recent investigation and current research (Storey, 1977).

Recently, the synergistic effect of the combination of low O_2 and high CO_2 tensions on Tribolium castaneum adults has been demonstrated (Calderon and Navarro, 1979). This work opens the possibilities of using relatively high O_2 concentrations when supplemented by CO_2, as a modified atmosphere formula in controlling storage insects. Further research along these lines is required.

ROLE OF TEMPERATURE

The time required to obtain a certain level of insect mortality exposed to a given atmospheric gas composition is dependent on the temperature of the environment. In fact, from the physiological aspects at normal atmospheres, development of insects can only occur within a fairly narrow range of temperatures. Developmental thresholds have been determined for a number of stored product insects at different stages of development (Birch, 1945; Howe, 1960). For example, for the egg-to-adult stage of Sitophilus oryzae, the threshold limits for development are between 15^{o} and $34^{o}C$, while for Rhyzopertha dominica these limits are between 18^{o} and $40^{o}C$ (Birch, 1945). Below or above these temperatures, complete mortality of insects is obtained, as determined by failure to hatch or emerge. Within the above mentioned limits, the rate of development is greatly affected by temperature (Howe, 1965).

It is well accepted that the effect of insecticidal treatment (especially for insecticides acting through the respiratory system like fumigants) is much more pronounced at higher temperatures (Monro, 1969). The effect of modified atmospheres seems to be very similarly dependent on the ambient temperature.

Fig. 1 demonstrates that at given atmospheric gas compositions, the higher the temperature - the shorter the exposure time needed to achieve 95% mortality of insects (Person and Sorenson, 1970; Storey, 1975 ; Storey, 1977). In an atmosphere of $<1.0\%$ O_2 and 9-9.5% CO_2, R. dominica adults were more tolerant than T. castaneum adults. The decrease in the number of hours required to obtain 95% mortality of the tested species, from 15^{o} to $21^{o}C$, is very pronounced.

This effect is shown to be similar in tendency for the three insect species depicted in Fig. 1, which differ in their susceptibility in the given gas concentration. In practice, these data should be considered very carefully. It is clear that much longer exposures will be needed, at a given gas composition,

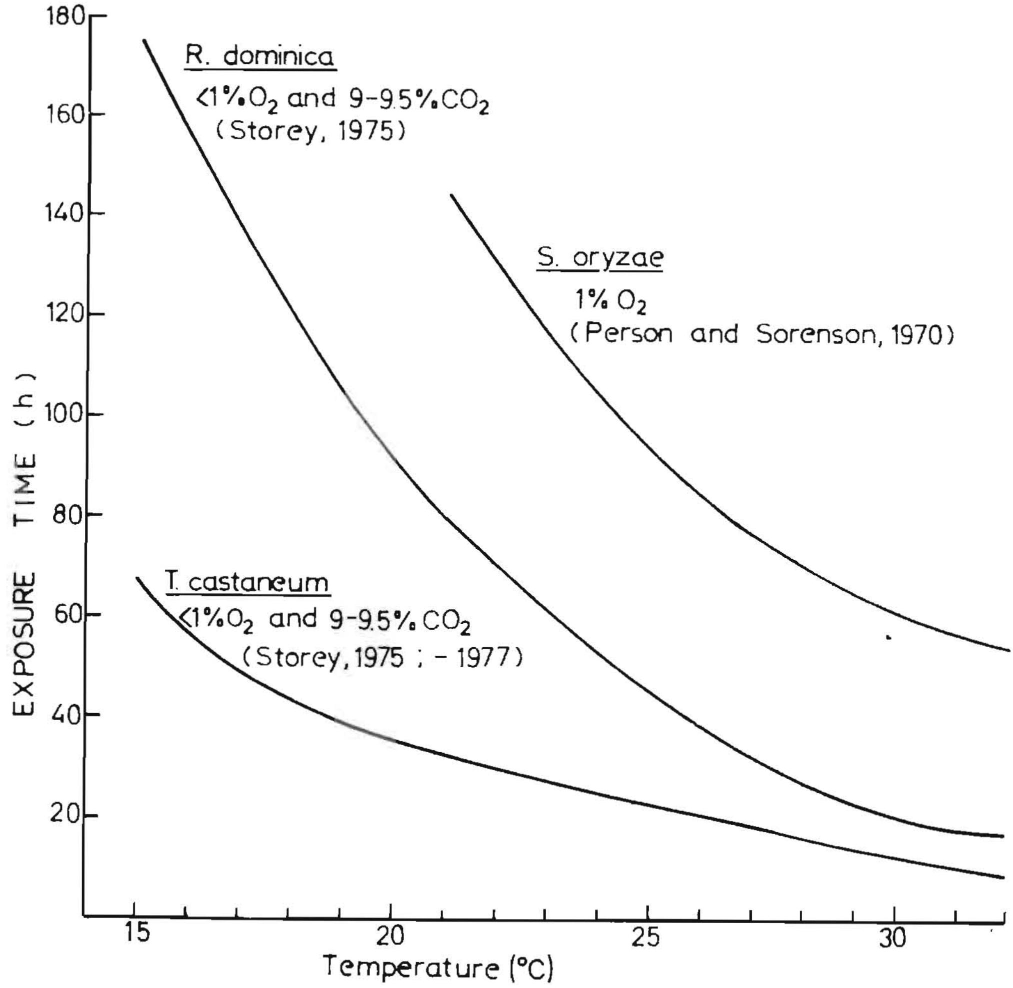

Fig. 1. Effect of temperature on exposure time required to produce 95% mortality of three stored product insects (adults) exposed to two atmospheric gas compositions.

to obtain effective control when low temperatures prevail in the grain bulk. Furthermore, since differences in temperature exist in the various parts of the grain bulk, the lowest temperature recorded should determine the length of the exposure time required for the treatment. In the use of controlled atmosphere treatment, the most resistant insect species found in the grain bulk to be treated should be considered.

ROLE OF RELATIVE HUMIDITY

Humidity influences the survival of insects mainly through the effect on their water content. Dry conditions appear to be generally unfavourable for the reproduction of most insects. However, most stored product insects can survive at very low humidities (Howe, 1965). The survival of insects under dry conditions depends on their maintaining a balance between the losses and gains of water (Edney, 1967).

Therefore, the means of maintaining water within certain limits in stored product insects is an important aspect of their structure and physiology (Navarro, 1978).

The role of relative humidity in producing mortality in insects by desiccation alone, when exposed to controlled atmospheres, requires further clarification.

The pronounced dependence of low O_2 or elevated CO_2 tensions on the relative humidity of the environment for producing a lethal atmosphere for several stored product insects, has been investigated (Jay et al., 1971; Navarro, 1978; Navarro and Calderon, 1974). Figure 2 demonstrates the role of relative humidity on adult emergence of Ephestia cautella pupae exposed to two atmospheric compositions (Navarro, 1974a). These data indicate that at 20-24% relative humidity, 3.2% O_2 or 4.3% CO_2 in air is needed to achieve complete mortality. However, at the same gas compositions but at higher relative humidities, E. cautella pupae could survive. These results, as well as data obtained by other authors (Jay et al., 1971; Navarro, 1978), indicate that the controlled atmosphere treatments could be more effective when the moisture content of the treated grain is low.

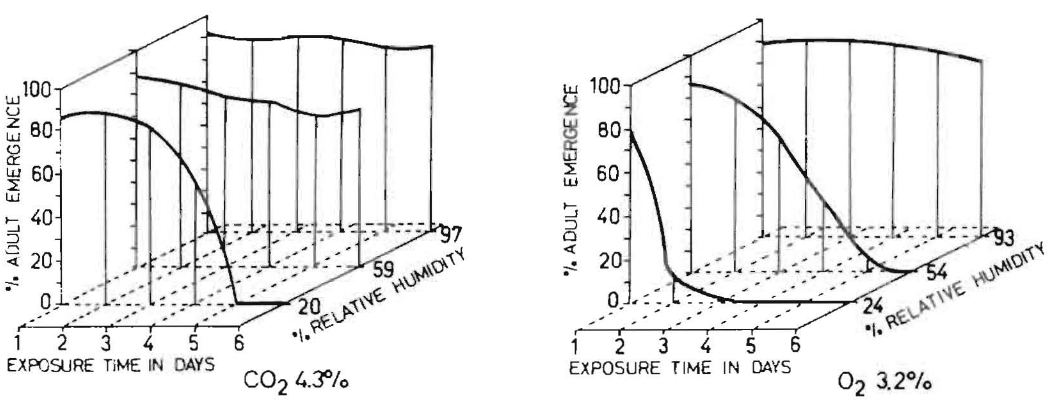

Fig. 2. The effect of O_2 and CO_2 at different relative humidities on adult emergence from E. cautella pupae at 26°C.

The moisture content of a stored product may vary over a considerable range and it is in equilibrium with the relative humidity of the intergranular air space of the grain bulk ecosystem. Due to the phenomenon of moisture migration, the moisture content of grain in some parts of the bulk may be considerably higher than in other remaining parts of the bulk. This also requires careful consideration so that extreme concentrations of gas should be applied to achieve effective control of insects found in grain of high moisture content.

PRACTICAL CONCLUSIONS

A number of field trials have been conducted using different atmospheric gas compositions (Banks, 1979). The effectiveness of the experimental trials using controlled atmospheres has been high, but complete mortality has not always been obtained (Jay and Pearman, 1973; Navarro et al., 1979; Shejbal et al., 1973). The reasons for the observed incomplete insect mortality have not been properly analyzed.

In field trials with controlled atmospheres, the approach has been based on maintaining the required gas composition within acceptable limits in a reasonably gastight silo. Efforts have been made to seal the silos to a degree which will prevent excessive use of gas mixtures (Banks and Annis, 1977). However, in practice, it is difficult and expensive to render a large structure completely gastight. Therefore, there is the possibility that surviving insect populations will aggregate around the leaks (Navarro et al., 1979).

One major problem that may arise from surviving insect populations is the development of resistance to modified atmospheres. Although resistant insect species have not yet been recorded from field populations, there are data indicating that stored grain pests have the genetic potential to develop resistance to CO_2 (Bond and Buckland, 1979).

Factors other than gastightness may also contribute to the observed incomplete insect control in large-scale modified atmosphere treatment. Prolonged exposures of several weeks are required for obtaining satisfactory results at low temperatures. Under certain conditions it seems to be impractical to maintain the required gas concentrations for such long periods of time, especially when the temperature is below the lower threshold limit for the development of the insect species infesting the grain.

Damp grain pockets in the bulk are also the cause of insect survival after controlled atmosphere treatment. Drying of the grain bulk for obtaining efficient insect control with modified atmospheres is not a practical proposition. Therefore, the moisture content of the grain should be seriously considered in determining the required gas concentrations and exposure times.

From the above discussion the following integrated insect control method is suggested: Controlled atmosphere treatment should be applied when high temperatures prevail in the grain, followed by aeration for reducing grain temperature. This sequence of treatments will provide a reasonable degree of insect control: The controlled atmosphere treatment will aim at obtaining the maximum possible insect mortality, while the cooling of the grain bulk (Navarro, 1974b) will contribute further protection by reducing the reproductive rate of the possible survivors of an insect population.

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