INTRODUCTION

Today, fumigants play a major role in the preservation of wide range of commodities of animal and plant origin (Monro, 1969). Of the range of stored commodities, cereal grains are of particular importance representing a primary source of food for world populations. Losses of grain constitute a serious international problem. Losses are caused by number of factors including insect attack, rodent infestation, deterioration due to fungi, feeding by birds and spoilage during handling all of which are interrelated (How, 1965).

Insect control in stored cereal grains and cereal products is achieved generally by a program incorporating sanitation measures supplemented by the use of residual insecticides, and fumigants. The principal fumigants used, on a world-wide basis, are methyl bromide and phosphine.

Phosphine has come into prominence in recent years as an effective fumigant to control insects in grains, flour, plant products, and prepared foods. It ranks as one of the most and highly toxic fumigants to stored product insects (Lindgren *et al*., 1958; Lindgren and Vincent, 1966; Bond and Monro, 1961 and Hole *et al*., 1976).

Lindgren *et al*. (1958) stated that hydrogen phosphide is effective as a fumigant against *Tribolium confusum*,

Sitophilus granarius, Trogoderma granarium, Rhizopertha dominica and Oryzaephilus surinamensis and readily penetrates flour or wheat.

No effect on seed germination has been observed, and preliminary results indicated no effect on baking quality. Sorption varies with the fumigant used, the commodity being fumigated, temperature and moisture content of the commodity. The rate of which sorption occurs and the amount sorbed determine the amount of the fumigant which remains in the gas phase and is available to the insect that is being fumigated (Lindgren and Vincent, 1959 & 1960; Ahmed, 1976 and Singh et al., 1983).

Bond and Dumas (1967) and Bruce et al. (1962) achieved no residues of phosphine even when PHOSTOXIN^{R} tablets were added to whole wheat flour immediately before baking and no appreciable amount of phosphine reacts with the flour. Vincent and Lindgren (1971) found that the drop in concentration of some fumigants in the presence of either wheat or corn was least for hydrogen phosphide followed by methyl bromide, ethylene dibromide and hydrocyanic acid. Sorption increased with increased load and moisture content of grain.

Phosphine showed, at higher concentrations, a narcotic action on adults of Sitophilus zeamais. With respect to the narcosis effect of phosphine, Bond et al. (1969)

observed that the rate of onset of narcosis appeared to be proportional to the concentration.

One of the major problems that has developed in many insect control programs in recent years concerns the resistance that is acquired when successive generations are exposed to toxic agents. Survivors from progressive selections can develop characteristics that will make the toxicant ineffective or uneconomical to use. Resistance to the fumigants methyl bromide, phosphine (champ and Dyte, 1976) and ethylene dibromide (Bond, 1973) has been found in field populations of stored-products insects in recent years.

El-Lakwah et al. (1991) mentioned that, the susceptiblity of some field strains of Tribolium castaneum and Sitophilus oryzae, collected from different Governorates in Egypt to phosphine, was studied in comparison to a laboratory strain of each insect species. Results revealed that the tolerance ratios for T. castaneum at the LC.$T_{99.9}$-levels and 26±1°C varied from 0.78 (for Cairo strain) to 2.24 times (for Menoufia strain). At 6±1°C the tolerance ratios varied also at the LC.$T_{99.9}$-levels from 0.92 (for Cairo strain) to 5.53 times (for Sharkia field strain). The tolerance ratios for S. oryzae at the LC.$T_{99.9}$-levels and 26±1°C varied from 0.57 (for Damietta field strain) to 1.82 times (for Kalyubia field strain).

At 6±1°C the tolerance ratios varied from 0.75 (for Kalyubia strain) to 2.12 times (for Behera strain), in comparison with the laboratory strain at the $LC.T_{99.9}$-level. Such differences in the susceptiblity of the field strains of the two insect species to phosphine could result in the failure of control program and should be given full consideration during practical fumigation.

Carbon dioxide, a normal component of the atmosphere that may accumulate in grain storages, is known to affect the respiration of insects and to enhance the toxicity of some fumigants.

Bond and Buckland (1979) tested the effect of adding CO_2 to a number of fumigants at 0°, 10° and 25°C using adults of S. granarius and Tribolium castaneum and fourth instar larvae of Tenebrioides mauritanicus. The fumigants used were acrylonitrile, methyl bromide, a mixture of these two, and phosphine and hydrogen cyanide. Results varied ranging from a seven-fold increase of the toxicity to T. castaneum of acrylonitrile in the presence of 30% CO_2 to no increase at all with hydrogen cyanide. The authors suggested the use of low concentrations of fumigants in controlled atmospheres employing CO_2 as a mean of reducing the concentration of CO_2 required, or of reducing the exposure times.

Desmarchelier (1984) found that for the adults of all six tested species S. granarius, S. oryzae, T. confusum, T. castaneum, T. granarium and R. dominica, the calculated or corrected values for mortality due to phosphine in mixture of 75% CO_2, 25% air and phosphine were significantly; less at both the LT_{50} and the LT_{99} levels, than those observed in phosphine alone. That is to say, phosphine synergized the toxicity of carbon dioxide against adults and larvae but not against pupae of S. oryzae. He also found that the action of carbon dioxide and phosphine was additive for the three external pupae, and in case of S. granarius pupae, but for S. oryzae the action between CO_2 and phosphine was antagonistic. The results for pupae of R. dominica showed synergistic effect, and an additive effect in the case of eggs at LT_{99} level for S. oryzae, S. granarius, T. granarium and R. dominica.

Wigglesworth (1965) suggested that high concentration of Co_2 may cause the muscle of spiracles to relax and spiracles to open, consequently more fumigant is taken up.

Kashi and Bond (1975) mentioned that CO_2 was found to potentiate the action of phosphine against a normal strain of T. confusum and against normal and resistant strains of S. granarius so that the length of the exposure period could be reduced.

El-Lakwah et al. (1991a) found that various carbon dioxide concentrations (20, 50 and 78%) applied alone against Sitotroga cerealella at 20 and 28°C showed a negligible effect on larval and a slight effect on pupal mortalities at short exposure periods, but the mortalities resulting at longer exposure time (24-72 hr) were found between 4-60% at the two test temperatures. Larval mortalities obtained from mixtures of LC_{50} of phosphine + carbon dioxide were significantly higher than those of each gas alone, whereby a synergistic action was proved for all exposure periods at 20°C and 28°C. An increase in pupal mortalities was achieved at all exposure periods with exception of 8 hr at 20°C, and an independent joint action was found at short and long exposures at 28°C. The same authors found (1991b) also that CO_2 showed a slight effect on the adult mortalities of T. castaneum and S. oryzae at 28 and 20°C for short exposure periods of 2, 4 and 8 hr, but the effect was high at longer exposure (24-72 hr) especially for 50 and 78% CO_2. Complete mortalities were recorded at all exposure periods by using the mixtures of CO_2 and the LC_{50} of phosphine against the test insects at 28°C.

Therefore, the aim of this work was to investigate the efficacy of phosphine and carbon dioxide alone as well as their mixtures against some important insect species causing