RESULTS AND DISCUSSION

1- Efficacy of CA of 30% CO_2 against the tested insect species at 18 ± 2°C and 55 ± 5% R.H. inside the various storage facilities:

1a- Efficacy of CA of 30 ± 5% CO_2 against the tested insect species at 18 ± 2°C, 55 ± 5% R.H. inside the closed steel bins at varying exposure periods:

The obtained results are presented in Table 1a. The results show clearly that percentage mortalities of the various insects and their developmental stages were increased with rising the exposure period.

S. oryzae:

For the adults of ***S. oryzae*** mortality values were 50.2 ± 3.1 and 100% after 3 and 7 day-exposure period, respectively. Egg percentage mortality was 15.2 ± 5.9% at 3 day-exposure and this value increased gradually to reach 100% at 35 day-exposure period. Larval percentage mortality was 20.3 ± 5.1% at 3 day-exposure and this value raised to 80.3 ± 1.9% at 21 days from treatment and reached complete kill after 28 day-exposure. Pupal percentage mortality was 16.1 ± 2.3% at 3 day-exposure period and raised to 94.0 ± 4.2% after 35 day-exposure and complete mortality was reached after 42 days post-treatment. Accordingly, the exposure time needed for achieving complete mortalities for the various stages of ***S. oryzae*** using CA of 30 ± 5% CO_2 at 18 ± 2°C inside the closed steel bins was at least 6 weeks. The results showed clearly that the pupal stage of ***S. oryzae*** was the most resistant to 30% CO_2, while the adult was the most sensitive.

Table (1a): Responses of the tested stages of various insect species to CA of 30 ± 5 % CO_2 in the closed steel bins at 18 ± 2 °C, 55 ±5% R.H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)								Control
		3	7	10	14	21	28	35	42	
S. oryzae	Adult	50.2± 3.1	100	100	100	100	100	100	100	0.0
	Egg	15.2±5.9	25.1±5.2	40.2±6.1	50.3±0.0	76.1±8.8	98.5±1.3	100	100	0.0
	Larva	20.3±5.1	33.6±2.4	50.1±4.2	60.3±4.2	80.3±1.9	100	100	100	0.0
	Pupa	16.1±2.3	28.3±2.1	30.2±6.1	38.4±4.1	60.2±6.1	81.1±1.9	94.0±4.2	100	0.0
R. dominica	Adult	40.3±2.1	80.3±2.1	100	100	100	100	100	100	0.0
	Egg	16.2±5.8	28.1±8.1	32.6±2.1	36.1±3.3	63.3±4.7	85.1±2.1	95.1±7.2	100	0.0
	Larva	18.1±2.3	26.1±4.1	50.2±6.1	60.1±6.2	75.3±3.1	90.1±4.2	100	100	0.0
	Pupa	16.1±4.2	24.3±3.2	30.4±3.2	35.1±1.9	60.2±6.6	80.3±3.1	93.1±2.1	100	0.0
T. castaneum	Adult	36.1±6.3	100	100	100	100	100	100	100	0.0
	Egg	25.2±3.1	50.3±2.4	86.2±3.1	100	100	100	100	100	0.0
	Larva	40.3±5.1	80.3±4.1	100	100	100	100	100	100	0.0
	Pupa	36.3±3.2	75.1±4.2	90.2±6.1	100	100	100	100	100	0.0
T. granarium larvae	Active	0.0	20.3±2.1	30.2±4.1	46.2±4.1	70.1±1.8	90.1±2.3	100	100	0.0
	diapause	0.0	6.9±2.4	20.3±4.2	26.5±3.1	50.4±2.3	80.1±6.1	90.3±2.4	100	0.0

R. dominica:

Percentage mortality of the adults of ***R. dominica*** at 3 day-exposure was 40.3 ± 2.1% and this value increased to reach complete kill at 10 day-exposure. Egg percentage mortality at 3 day-exposure was 16.2 ± 5.8% and this value reached 100% kill at 42 day-exposure. Larval percentage mortality was 18.1 ± 2.3% at 3 day-exposure and this figure reached complete kill at 35 days post-treatment. Pupal percentage mortality was 16.1 ± 4.2% at 3 day-exposure and this value increased gradually to reach 100% at 42 day-exposure. Accordingly, to obtain 100% mortalities for the various stages of ***R. dominica***, the exposure time needed was at least 6 weeks. The obtained data indicated that the adults and larvae of ***R. dominica*** were more susceptible to 30% CO_2 than the eggs and pupae.

T. castaneum:

At 3 day-exposure, percentage mortalities of the adult, egg, larva and pupa of ***T. castaneum*** were 36.1 ± 6.3, 25.2 ± 3.1, 40.3 ± 5.1 and 36.3 ± 3.2%, respectively. In case of the adult complete kill was recorded after 7 days of exposure, while in case of egg and pupa complete kill were recorded after 14 day-exposure, while in case of larva complete mortalities were recorded at 10 day-exposure. The exposure time for achieving 100% kill for the various stages of ***T. castaneum*** using the above mentioned CA at 18 ± 2°C was at least 2 weeks. Under this treatment, the eggs and pupae of ***T. castaneum*** were more resistant of CO_2 than the larvae and adults.

T. granarium:

At 3 day-exposure nil percentage mortalities were recorded

for the active and diapausing larvae of ***T. granarium,*** but these values increased with the increase of the exposure time to reach 100% mortality at 35 and 42 day-exposure for the active and diapause larvae, respectively. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 6 weeks. This result indicated clearly that the diapausing larvae were more resistant to this CA than the active one.

In summary, the results showed clearly, that an exposure period of at least 6 weeks is necessary to obtain total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using CA of 30 ± 5% inside the closed steel bins at grain temperature of 18 ± 2°C.

1b- Efficacy of CA of 30 ± 5% CO_2 against the tested insect species at 18 ± 2°C, 55 ± 5% R.H. inside the closed fiberglass bins at varying exposure periods:

The obtained results are listed in Table 1b. Clearly, the results shown in this table revealed that percentage mortalities of the various insects and their developmental stages raised gradually with the increase of the exposure period of the insects to CO_2 inside the closed fiberglass bins.

S. oryzae:

At 3 day-exposure, percentage mortalities of the adult, egg, larva and pupa of ***S. oryzae*** were 20.1 ± 2.3, 11.2 ± 3.1, 13.3 ± 2.0 and 9.6 ± 1.6%, respectively. These values increased with the increase of the exposure period to reach complete kill at 14, 60, 50 and 60 day-exposure for the mentioned immature stages, respectively. The exposure time required for achieving complete

Table (1b): Responses of the tested stages of various insect species to CA of 30 ± 5 % CO_2 in the closed fiberglass bins at 18 ± 2 °C, 55 ±5% R.H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)									Control
		3	7	14	21	28	35	42	50	60	
S. oryzae	Adult	20.1±2.3	60.2±3.1	100	100	100	100	100	100	100	0.0
	Egg	11.2±3.1	18.2±3.1	25.3±1.4	36.3±7.1	50.3±4.1	71.2±1.6	80.2±2.1	97.3±6.1	100	0.0
	Larva	13.3±2.0	20.4±5.1	36.3±2.6	53.4±2.1	70.4±3.2	85.3±2.4	93.4±3.1	100	100	0.0
	Pupa	9.6±1.6	15.1±2.6	24.6±3.1	33.3±2.0	43.1±1.6	66.6±4.1	80.2±2.5	93.1±3.2	100	0.0
R. dominica	Adult	20.2±3.1	55.6±3.1	90.4±8.1	100	100	100	100	100	100	0.0
	Egg	10.1±2.4	13.8±4.6	26.1±3.2	33.1±3.1	50.6±3.4	70.3±6.1	80.1±2.6	100	100	0.0
	Larva	8.1±3.1	20.2±4.1	41.3±2.6	50.3±2.3	73.4±2.1	86.4±3.1	89.1±3.1	100	100	0.0
	Pupa	6.4±2.1	15.2±3.1	24.3±4.1	33.6±2.0	46.1±1.6	66.2±2.4	77.3±2.0	91.1±6.1	100	0.0
T. castaneum	Adult	20.2±3.1	50.0±3.1	95.0±2.0	100	100	100	100	100	100	0.0
	Egg	13.4±4.1	22.1±2.6	40.1±3.2	71.3±6.1	85.3±4.1	100	100	100	100	0.0
	Larva	20.2±2.6	66.1±4.6	85.3±2.0	95.1±6.1	100	100	100	100	100	0.0
	Pupa	18.1±4.1	50.2±3.1	70.6±5.1	88.2±3.1	97.3±2.6	100	100	100	100	0.0
T. granarium larvae	Active	0.0	9.6±3.2	16.3±3.1	36.1±1.1	50.1±1.6	80.3±2.1	97.1±1.4	100	100	0.0
	diapause	0.0	0.0	9.6±3.1	26.1±1.1	40.1±3.0	60.2±4.1	75.2±6.1	97.4±7.3	100	0.0

kill for the various stages of ***S. oryzae*** using CA of 30 ± 5% CO_2 at 18 ± 2°C inside the closed fiberglass bins was found to be at least 8 weeks. Also, the adult of S. oryzae were the most sensitive stage to this CA.

R. dominica:

Percentage mortality of the adult of ***R. dominica*** was 20.2 ± 3.1% at 3 day-exposure and this value reached 100% mortality after 21 days of exposure. Egg percentage mortality at 3 day-exposure was 10.1 ± 2.4% and this value increased to complete kill at 50 day-exposure. Larval percentage mortality at 3 day-exposure was 8.1 ± 3.1% and this value raised to 100% at 50 day-exposure. Pupal percentage mortality was 6.4 ± 2.1 at 3-day-exposure and this value increased to reach 100% at 60 day-exposure. Under this condition, to obtain 100% mortalities for the various stages of ***R. dominica,*** the needed exposure time was at least 8 weeks. The results showed clearly that the pupae were the most resistant followed by the eggs and larvae, while the adult was the most sensitive stage.

T. castaneum:

Adult percentage mortality of ***T. castaneum*** was 20.3 ± 3.1% at 3 day-exposure and this value increased to 100% at 21 day-exposure. Egg percentage mortality was 13.4 ± 4.1% at 3 day-exposure and reached complete kill after 35 day-exposure. Larval percentage mortality was 20.2 ± 2.6% at 3 day-exposure and 100% kill was achieved at 28 day post-treatment. Pupal percentage mortality was 18.1 ± 4.1% at 3 day-exposure and this value reached 100% at 35 day-exposure. The exposure time nedeed for achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions were at least 5 weeks.

Pupae and eggs were more resistant to this CA than the larvae and adult stages.

T. granarium:

Nil mortalities were recorded for the active and diapausing larvae of ***T. granarium*** at 3 day-exposure, but complete mortality was achieved at 50 and 60 day post-treatment for the active and diapausing larvae, respectively. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 9 weeks, and active larvae were more sensitive than diapausing one.

Briefly, the results showed clearly, that an exposure period of at least 9 weeks is needed to achieve total extinction of the adults and Immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using CA of 30 ± 5% CO_2 inside the closed fiberglass bins, at grain temperature of 18 ± 2°C.

1c- Efficacy of CA of 30 ± 5% CO_2 against the tested insect species at 18 ± 2°C, 55 ± 5% R.H. inside the closed metal drums at varying exposure periods:

The obtained results are presented in Table 1c. The results show that mortality values raised with increasing the exposure period.

S. oryzae:

Adult percentage mortality of ***S. oryzae*** was 30.2 ± 3.1% at 3 day-exposure and this value raised to 90.2 ± 2.1% at 7 day-exposure and reached complete kill after 10 day-exposure period. At 3 day-exposure, the percentage mortalities of egg, larva and pupa were 15.1 ± 6.1, 18.3 ± 2.6 and 15.0 ± 0.0%, respectively.

Table (1c): Responses of the tested stages of various insect species to CA of 30 ± 5 % CO_2 in the closed metal drums at 18 ± 2 °C, 55 ±5% R.H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)									Contro
		3	7	10	14	21	28	35	42	50	
S. oryzae	Adult	30.2±3.1	90.2=2.1	100	100	100	100	100	100	100	0.0
	Egg	15.1±6.1	21.6=3.4	33.2±6.1	40.2±3.1	66.3±4.1	88.1±3.4	97.1±2.6	100	100	0.0
	Larva	18.3±2.6	26.2=3.1	40.2±4.1	50.2±6.1	71.3±4.6	80.4±2.6	88.2±4.1	100	100	0.0
	Pupa	15.0±0.0	20.2=6.1	26.4±6.1	36.2±4.1	56.3±1.9	70.3±1.6	77.2±4.1	96.3±2.5	100	0.0
R. dominica	Adult	30.1±2.6	75.3=6.1	100	100	100	100	100	100	100	0.0
	Egg	12.8±3.1	21.4=3.6	26.4±3.4	30.2±4.1	56.4±2.1	77.3±4.1	90.2±6.1	99.1±1.2	100	0.0
	Larva	16.3±2.1	23.6=3.1	40.2±6.1	50.2±3.1	66.3±4.1	76.4±6.1	100	100	100	0.0
	Pupa	14.1±2.6	21.2=6.1	26.1±2.3	30.2±3.4	65.1±4.6	70.6±3.4	89.3±4.1	93.0±3.0	100	0.0
T. castaneum	Adult	40.2±3.1	66.2=2.6	100	100	100	100	100	100	100	0.0
	Egg	20.2±6.1	40.3=7.1	76.3±2.1	100	100	100	100	100	100	0.0
	Larva	33.6±6.1	70.1=3.4	100	100	100	100	100	100	100	0.0
	Pupa	30.6±3.1	66.3=4.1	88.2±7.1	100	100	100	100	100	100	0.0
T. granarium larvae	Active	0.0	20.2=6.1	36.6±3.1	46.4±3.1	67.6±4.1	83.2±6.1	90.4±2.3	100	100	0.0
	diapause	0.0	13.1=2.4	16.2±6.1	26.8±3.2	50.3±4.1	77.4±2.1	86.4±6.1	96.4±2.3	100	0.0

These values increased to 100% at 42, 42 and 50 day-exposure, respectively. Accordingly, the exposure time required for achieving complete kill for the various stages of ***S. oryzae*** using CA of 30 ± 5% CO_2 at 18 ± 2°C inside the closed metal drums was at least 7 weeks.

R. dominica:

Adult percentage mortality of ***R. dominica*** was 30.1 ± 2.6% at 3 day-exposure and this value increased to 75.3 ± 6.1% at 7 day-exposure and reached complete kill after 10 day post-treatment. Egg percentage mortality was 12.8 ± 3.1% at 3 day-exposure and reached 100% after 50 day-exposure. Larval percentage mortality was 16.3 ± 2.1% at 3 day-exposure and 100% mortality was achieved at 35 day-exposure. Pupal percentage mortality was 14.1 ± 2.6% at 3 day-exposure and complete kill at 50 day-exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominica,*** the exposure time needed was at least 7 weeks.

T. castaneum:

The obtained percentage mortalities at 3 day-exposure were 40.2 ± 3.1, 20.2 ± 6.1, 33.6 ± 6.1 and 30.6 ± 3.1% for the adult, egg, larva and pupa of ***T. castaneum,*** respectively. Complete mortalities were achieved at 10 day-exposure for the adult and larval stages and 14 day-exposure for the egg and pupal stages. The exposure time for achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions was accordingly at least 2 weeks.

T. granarium:

Percentage mortalities obtained for the active and diapausing larvae of ***T. granarium*** at 7 day-exposure were 20.2 ±

6.1 and 13.1 ± 2.4%, respectively. These values increased to 100% at 42 and 50 day-exposure for the active and diapausing larvae, respectively. The results showed clearly that the diapausing larvae were more resistant than the active one and the exposure time needed to achieve complete mortalities for both larvae of ***T. granarium*** under the above conditions was at least 7 weeks.

In conclusion, the results showed clearly, that an exposure period of at least 7 weeks is required to obtain total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using CA of 30 ± 5% CO_2 inside the closed metal drums at grain temperature of 18 ± 2°C.

2- Efficacy of CA of 30 % CO_2 against the tested insect species at 28 ± 2°C and 55 ± 5% R.H. inside the various storage facilities:

2a- Efficacy of CA of 30 ± 5% CO_2 against the tested insect species at 28 ± 2°C, 55 ± 5% R.H. inside the closed steel bins at varying exposure periods:

The results are presented in Table 2a. The results show clearly that percentage mortalities of the various insects and their developmental stages were increased with rising the exposure period.

S. oryzae:

At 3 day-exposure, percentage mortalities of the adult, egg, larva and pupa of ***S. oryzae*** were 60.2 ± 3.1, 28.2 ± 2.1, 26.3 ± 1.6and 21.6 ± 3.1%, respectively. These values increased with rising the exposure period to reach complete kill at 7, 28, 28 and

Table (2a): Responses of the tested stages of various insect species to CA of 30 ± 5% CO_2 in the closed steel bins at 28 ±2 °C, 55 ±5% R.H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)							Control
		3	7	10	14	21	28	35	
S. oryzae	Adult	60.2±3.1	100	100	100	100	100	100	0.0
	Egg	28.2±2.1	35.3±1.6	50.2±3.4	66.3±2.4	83.3±4.1	100	100	0.0
	Larva	26.3±1.6	40.2±2.0	58.3±4.6	66.1±4.1	85.1±2.3	100	100	0.0
	Pupa	21.6±3.1	32.6±2.4	44.3±5.1	56.3±5.1	76.4±3.1	93.0±4.2	100	0.0
R. dominica	Adult	50.2±3.1	100	100	100	100	100	100	0.0
	Egg	26.2±3.1	35.1±2.4	42.6±3.1	55.6±4.1	80.3±2.6	100	100	0.0
	Larva	30.2±2.1	50.1±1.6	61.2±3.4	85.2±2.4	93.1±3.2	100	100	0.0
	Pupa	24.8±2.1	29.3±6.1	40.2±3.2	53.3±4.1	76.2±2.1	88.1±5.1	100	0.0
T. castaneum	Adult	44.2±3.1	100	100	100	100	100	100	0.0
	Egg	30.2±3.1	70.3±2.1	90.2±3.1	100	100	100	100	0.0
	Larva	50.0±2.6	83.3±4.1	100	100	100	100	100	0.0
	Pupa	44.2±6.1	80.2±3.1	96.2±3.1	100	100	100	100	0.0
T. granarium larvae	Active	6.3±0.0	20.3±4.1	33.2±4.1	55.1±2.1	75.1±2.1	95.3±2.3	100	0.0
	diapause	0.0	9.6±4.1	26.3±2.1	33.2±3.1	55.1±2.1	86.0±3.0	100	0.0

35 day-exposure for the mentioned immature stages, respectively. This result indicated clearly that the pupal stage of ***S. oryzae*** was the most resistant of CO_2 followed by the larvae and eggs, while the adult stage was the most sensitive. The exposure time required for achieving compete kill for the various stages of ***S. oryzae*** using CA of 30 ± 5% CO_2 at 28 ± 2°C inside the closed steel bins was at least 5 weeks.

R. dominica:

Percentage mortality of the adult of ***R. dominica*** was 50.2 ± 3.1% at 3 day-exposure and this value reached 100% mortality after 7 days of exposure. Egg percentage mortality at 3 day-exposure was 26.2 ± 3.1% and this value increased to complete kill at 28 day-exposure. Larval percentage mortality at 3 day-exposure was 30.2 ± 2.1% and this value raised to 100% at 28 day-exposure. Pupal percentage mortality was 24.8 ± 2.1% at 3 day-exposure and this value increased to reach 100% at 35 day-exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominiea,*** the required exposure time was at least 5 weeks. Also, the pupal stage was more resistant to this CA than larvae and eggs, while the adult was the most sensitive.

T. castaneum:

Adult percentage mortality of ***T. castaneum*** was 44.2 ± 3.1 % at 3 day-exposure and this value increased to 100% at 7 day-exposure. Egg percentage mortality was 30.2 ± 3.1% at 3 day-exposure and reached complete kill after 14 day-exposure. Larval percentage mortality was 50.0 ± 2.6% at 3 day-exposure and 100% kill was achieved at 10 day post-treatment. Pupal percentage mortality was 44.2 ± 6.1% at 3 day-exposure and this value reached 100% at 14 day-exposure. The exposure time for

achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions was at least 2 weeks.

T. granarium:

The recorded mortalities for the active and diapausing larvae of ***T. granarium*** at 3 day-exposure were 6.3 ± 0.0 and 0.0 , respectively. These values increased to complete mortality at 35 day post-treatment for the both larval instars. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 5 weeks. Also active larvae were more sensitive than diapausing one.

Briefly, the results showed clearly, that an exposure period of at least 5 weeks is needed to obtain total extinction of the population of the populations of the adults and immature stages of S. ***oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using CA of 30 ± 5% CO_2 inside the closed steel bins at grain temperature of 28 ± 2°C.

2b- Efficacy of CA of 30 ± 5% CO_2 against the tested insect species at 28 ± 2°C, 55 ± 5% R.H. inside the closed fiberglass bins at varying exposure periods:

The obtained results are listed in Table 2b. Clearly, the results given in this table show that the percentage mortalities raised gradually with the increase of the exposure period of the insects to CO_2 inside the bins.

S. oryzae:

Adult percentage mortality of ***S. oryzae*** was 40.2 ± 3.0% at 3 day xposure nd his alue aised o 0.1 .1% t ay-exposure and reached complete kill after 14 day-exposure period.

Table (2b): Responses of the tested stages of various insect species to CA of 30 ± 5 % CO_2 in the closed fiberglass bins at 28 ± 2 °C, 55 ±5% R.H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)								Control
		3	7	14	21	28	35	42	50	
S. oryzae	Adult	40.2±3.0	80.1±3.1	100	100	100	100	100	100	0.0
	Egg	19.6±2.4	25.1±2.1	28.3±3.1	46.4±3.1	66.2±2.3	83.1±1.6	89.1±7.2	100	0.0
	Larva	21.1±2.4	32.6±3.1	50.2±2.6	69.2±3.1	81.1±4.1	100	100	100	0.0
	Pupa	15.1±3.2	24.1±3.2	38.1±4.2	43.6±6.1	61.4±2.1	80.3±4.0	88.1±3.4	100	0.0
R. dominica	Adult	25.1±6.1	60.2±3.2	100	100	100	100	100	100	0.0
	Egg	18.3±3.1	23.1±1.9	35.2±2.0	41.2±4.1	62.3±1.6	77.3±2.4	83.3±3.1	100	0.0
	Larva	13.3±4.1	26.4±3.6	45.6±3.1	66.1±2.0	79.0±4.1	90.1±1.6	95.3±2.1	100	0.0
	Pupa	17.3±2.1	20.5±3.1	31.4±2.6	40.2±4.1	60.3±3.2	77.8±1.2	83.1±3.1	100	0.0
T. castaneum	Adult	20.2±3.1	60.2±3.1	100	100	100	100	100	100	0.0
	Egg	20.1±4.1	26.1±2.1	71.1±1.3	90.1±2.3	100	100	100	100	0.0
	Larva	28.3±5.1	70.3±3.1	90.2±3.1	100	100	100	100	100	0.0
	Pupa	25.2±3.4	60.1±1.6	86.2±5.3	95.2±6.1	100	100	100	100	0.0
T. granarium larvae	Active	0.0	11.2±4.2	27.3±1.4	50.3±3.2	75.1±2.1	95.0±1.9	100	100	0.0
	diapause	0.0	3.3±2.0	16.3±2.3	36.2±1.6	66.2±2.4	80.1±3.1	90.0±5.0	100	0.0

At 3 day-exposure, the percentage mortalities of egg, larva and pupa were 19.6 ± 2.4, 21.1 ± 2.4 and 15.1 ± 3.2%, respectively. These values increased to 100% at 50, 35 and 50 day-exposure, respectively. The exposure time for achieving complete control for the various stages of ***S. oryzae*** using CA of 30 ± 5% CO_2 at 18 ± 2°C inside the closed fiberglass bins was at least 7 weeks.

R. dominica:

Adult percentage mortality of ***R. dominica*** was 25.1 ± 6.1% at 3 day-exposure and this value raised to 60.2 ± 3.2% at 7 day-exposure and reached complete mortality after 14 day post-treatment. Egg percentage mortality was 18.3 ± 3.1% at 3 day-exposure and reached 100% after 50 day-exposure. Larval percentage mortality was 13.3 ± 4.1% at 3 day-exposure and 100% kill was achieved at 50 day-exposure. Pupal percentage mortality was 17.3 ± 2.1% at 3 day-exposure and complete kill at 50 day-exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominica,*** the necessary exposure time was at least 7 weeks.

T. castaneum:

The obtained percentage mortalities at 3 day-exposure were 20.2 ± 3.1, 20.1 ± 4.1, 28.3 ± 5.1 and 25.2 ± 3.4% for the adult, egg, larva and pupa of ***T. castaneum,*** respectively. Complete mortalities were obtained at 14, 28, 21 and 28 day-exposure for the adult, egg, larval and pupal stages, respectively. The exposure time for achieving 100% mortality for the various stages of ***T. castaneum*** using the above conditions was accordingly at least 3 weeks.

T. granarium:

Percentage mortalities obtained for the active and

diapausing larvae of ***T. granarium*** at 7 day-exposure were 11.2 ± 4.2 and 3.3 ± 2.0%, respectively. These values increased to 100% at 42 and 50 day-exposure for the active and diapausing larvae, respectively. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions must extended to at least 7 weeks.

In summary, the results showed clearly, that an exposure period of at least 7 weeks is necessary to achieve total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneun*** and ***T. granarium*** by using CA of 30 ± 5% CO_2 inside the closed fiberglass bins at grain temperature of 28 ± 2°C.

2c- Efficacy of CA of 30 ± 5% CO_2 against the tested insect species at 28 ± 2°C, 55 ± 5% R.H. inside the closed metal drums at varying exposure periods:

The obtained results are presented in Table 2c. The results show that mortality values increased by extending the exposure period.

S. oryzae:

For the adult of ***S. oryzae*** the mortality value was 50.1 ± 2.4 and 100% at 3 and 7 day-exposure, respectively. Egg percentage mortality was 22.3 ± 2.1% at 3 day-exposure and this value increased gradually to reach 100% at 42day-exposure period. Larval percentage motility was 24.3 ± 1.0% at 3 day-exposure and this value raised to 71.6 ± 2.4% at 21 days from treatment and reach complete kill after 42 day-exposure. Pupal percentage mortality reach 20.2 ± 1.0% at 3 day-exposure period and raised to 73.6 ± 2.4% after 21 day-exposure and this value

Table (2c): Responses of the tested stages of various insect species to CA of 30 ± 5 % CO_2 in the closed metal drums at 28 ± 2 °C, 55 ±5% R.H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)								Contro
		3	7	10	14	21	28	35	42	
S. oryzae	Adult	50.1±2.4	100	100	100	100	100	100	100	0.0
	Egg	22.3±2.1	30.4±3.1	44.2±3.1	56.2±1.6	71.6±2.4	90.2±1.9	97.2±3.1	100	0.0
	Larva	24.3±1.0	36.3±2.4	51.2±2.4	60.3±2.4	82.3±3.4	100	100	100	0.0
	Pupa	20.2±1.0	30.1±6.9	40.3±6.1	46.1±3.4	73.6±2.4	86.2±4.1	96.1±2.3	100	0.0
R. dominica	Adult	40.2±2.4	80.1±2.0	100	100	100	100	100	100	0.0
	Egg	20.8±5.8	26.4±3.1	36.8±2.6	51.4±3.4	73.6±2.4	88.1±6.1	100	100	0.0
	Larva	25.3±3.4	33.2±4.1	43.2±7.1	60.3±2.6	80.4±3.4	95.6±2.6	100	100	0.0
	Pupa	20.6±1.9	26.1±2.5	33.2±6.1	50.4±3.1	70.6±2.6	83.1±2.1	95.2±3.1	100	0.0
T. castaneum	Adult	40.1±3.2	76.4±1.6	100	100	100	100	100	100	0.0
	Egg	26.1±3.4	60.2±2.6	80.2±6.1	100	100	100	100	100	0.0
	Larva	40.2±3.1	80.2±6.1	100	100	100	100	100	100	0.0
	Pupa	40.1±1.1	71.2±3.4	90.1±2.4	100	100	100	100	100	0.0
T. granarium larvae	Active	0.0	16.2±3.1	30.1±2.3	50.2±3.1	70.2±3.4	92.3±4.1	100	100	0.0
	diapause	0.0	9.6±6.1	16.4±2.1	31.1±2.3	50.0±3.1	80.2±3.1	97.1±2.3	100	0.0

reached 100% kill at 42 days post-treatment. Consequently, the exposure time needed for achieving complete kill for the various stages of ***S. oryzae*** using CA of 30 ± 5% CO_2 at 28 ± 2°C inside the closed metal drums was at least 6 weeks.

R. dominica:

Percentage mortality of the adult of ***R. dominica*** at 3 day-exposure was 40.2 ± 2.4% and this value increased to complete kill at 10 day-exposure. Egg percentage mortality at 3 day-exposure was 20.8 ± 5.8% and this value reached 100% kill at 35 day-exposure. Larval percentage mortality was 25.3 ± 3.4% at 3 day-exposure and this figure reached complete kill at 35 days post-treatment. Pupal percentage mortality was 20.6 ± 1.9% at 3 day-exposure and this value increased gradually to reach 100% at 42 day-exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominica,*** the exposure time was found to be at least 6 weeks.

T. castaneum:

At 3 day-exposure, percentage mortalities of the adult, egg, larva and pupa of ***T. castaneum*** were 40.1 ± 3.2, 26.1 ± 3.4, 40.2 ± 3.1 and 10.1 ± 1.1%, respectively. In case of the adult and larval stages, complete kill was recorded after 10 days of exposure, while in case of the egg and pupal stages complete kill were recorded after 14 day-exposure. The exposure time for achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions was at least 2 weeks.

T. granarium:

At 3 day-exposure nil percentage mortalities were recorded for the active and diapausing larvae of ***T. granarium,*** but these values increased with the increase of the exposure time to reach

100% mortality at 35 and 42 day-exposure for the active and diapause larvae, respectively. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 6 weeks.

In conclusion, the results showed clearly, that an exposure period of at least 6 weeks is necessary for achieving the total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using CA of 30 ± 5% CO_2 inside the closed metal drums at grain temperature of 28 ± 2°C.

-Loss of 30% CO_2 concentrations inside the various storage facilities at different exposure periods during summer and winter times:

Table (3 a&b) & fig (6&7) showed the change in CO_2 concentrations inside the different storage facilities at winter times as well as during summer times. This result indicated clearly the standard of gas tightness of the tested storage facilities showing the highest gastightness for the steel bins, and the lowest for the fiberglass bins.

3-Efficacy of CA of 60% CO_2 against the tested insect species at 18 ± 2°C and 55 ± 5% R.H. inside the various storage facilities:

3a- Efficacy of CA of 60 ± 5% CO_2 against the tested insect species at 18 ± 2°C. 55 ± 5% R.H. inside the closed steel bins at varying exposure periods:

The obtained results are given in Table 4a. The results show clearly that percentage mortalities of the various insects and

Table (3a): Concentrations of 30% CO_2 inside the various storage facilities at different exposure periods during winter times.

Storage facilities	CO_2 concentration at various exposure periods (days)						
	3	7	14	21	28	35	42
Closed steel bins	30	30	30	30	29	29	29
Closed fiberglass bins	30	28	27	24	20	17	14
Closed metal drums	30	30	30	29	29	28	28

Table (3b): Concentrations of 30% CO_2 inside the various storage facilities at different exposure periods during summer times.

Storage facilities	CO_2 concentration at various exposure periods (days)					
	3	7	14	21	28	35
Closed steel bins	30	30	29	29	29	28
Closed fiberglass bins	30	26	25	22	18	13
Closed metal drums	30	30	29	29	28	27

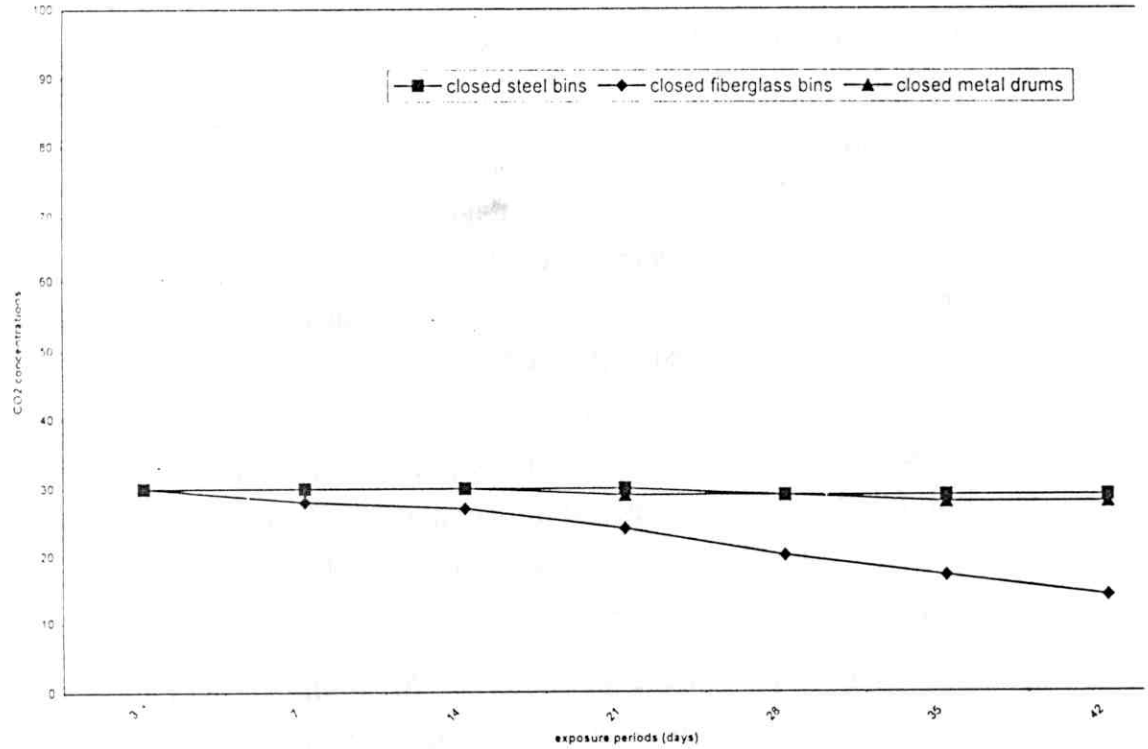

Fig (4): Concentrations of 30% CO_2 inside the different stored facilities at winter times.

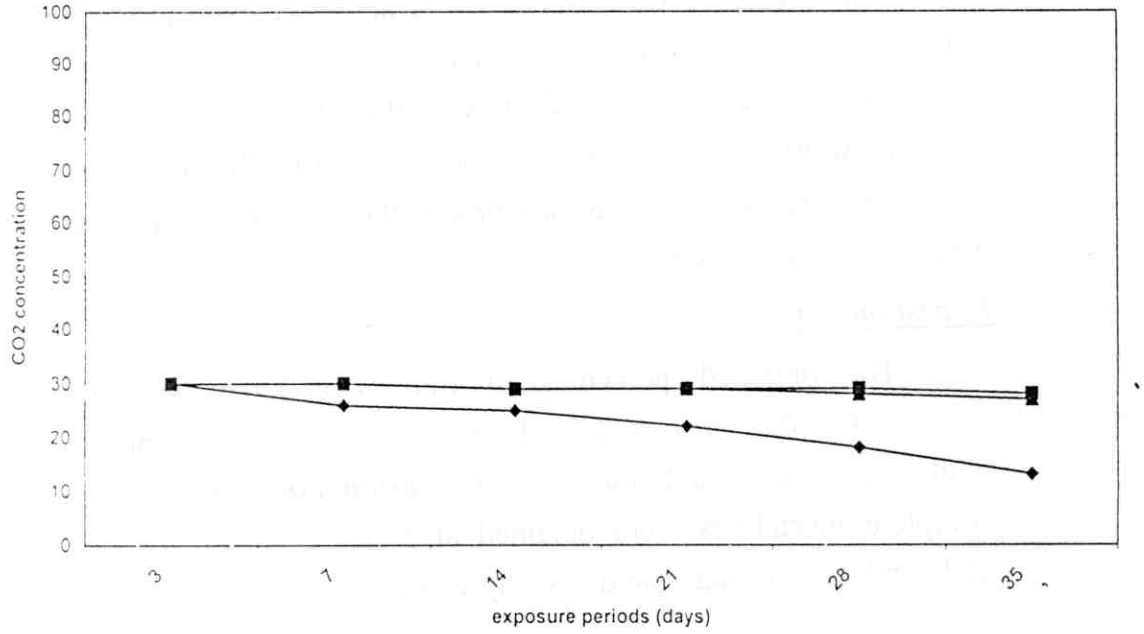

Fig (5): Concentrations of 30% CO_2 inside the different stored facitities at summer times.

their immature stages were increased with rising the exposure period.

S. oryzae:

At 2 day-exposure, percentage mortalities of the adult, egg, larva and pupa of ***S. oryzae*** were 83.1 ± 2.6, 32.1 ± 3.6, 35.6 ± 3.2 and 30.5 ± 3.8%, respectively. These values increased with the increase of the exposure period to reach complete kill at 3, 28, 21 and 35 day-exposure for the mentioned immature stage, respectively. The exposure time required for achieving complete kill for the various stages of ***S. oryzae*** using CA of 60 ± 5% CO_2 at 18 ± 2°C inside the closed steel bins was at least 5 weeks.

R. dominica:

Adult percentage mortality of ***R. dominica*** was 62.7 ± 0.0% at 2 day-exposure and this value raised to 95.6 ± 3.1% at 3 day-exposure and reached complete mortality after 5 day post-treatment. Egg percentage mortality was 36.1 ± 6.0% at 2 day-exposure and reached 100% after 28 day-exposure. Larval percentage mortality was 35.4 ± 6.7% at 2 day-exposure and 100% kill was achieved at 21 day-exposure. Pupal percentage mortality was 30.4 ± 6.1% at 2 day-exposure and complete kill at 35 day-exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominica,*** the necessary exposure time was at least 5 weeks.

T. castaneum:

The obtained percentage mortalities at 2 day-exposure were 50.0 ± 0.0, 30.1 ± 2.4, 74.6 ± 2.3 and 60.0 ± 1.9% for the adult, egg, larva and pupa of ***T. castaneum,*** respectively. Complete mortalities were obtained at 5 day-exposure for the adult and larval stages and 10 day-exposure for the egg stage,

while for the pupal stages this time was 7 days exposure period. The exposure time for achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions was around 1.5 week.

T. granarium:

Percentage mortalities obtained for the active and diapausing larvae of ***T. granarium*** at 7 day-exposure were 39.6 ± 0.0 and 26.4 ± 1.1%, respectively. These values increased to 100% at 28 and 35 day-exposure or he ctive nd diapause larvae, respectively. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 5 weeks.

In conclusion, the results showed clearly, that an exposure period of at least 5 weeks is necessary to obtain total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using CA of 60 ± 5% CO_2 inside the closed steel bins at grain temperature of 18 ± 2°C.

3b- Efficacy of CA of 60 ± 5% CO_2 against the tested insect species at 18 ± 2°C, 55 ± 5% R.H. inside the closed fiberglass bins at varying exposure periods:

The obtained results are listed in Table 4b. Clearly, the results given in this table show that the percentage mortalities raised gradually with the increase of the exposure period of the insects to CO_2 inside the bins.

S. oryzae:

Adult percentage mortality of ***S. oryzae*** was 40.1 ± 6.1% at 2 day-exposure and this value raised to 92.4 ± 3.0% at 5 day-

Table (4a): Responses of the tested stages of various insect species to CA of 60 ± 5 % CO_2 in the closed steel bins at 18 ± 2 °C, 55 ±5% R.H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)									Control
		2	3	5	7	10	14	21	28	35	
S. oryzae	Adult	83.1±2.6	100	100	100	100	100	100	100	100	0.0
	Egg	32.1±3.6	40.2±1.1	60.2±3.1	67.2±3.2	78.2±6.1	84.2±4.1	93.2±6.1	100	100	0.0
	Larva	35.6±3.2	40.6±4.1	55.2±4.1	70.2±4.6	80.2±1.1	90.1±2.4	100	100	100	0.0
	Pupa	30.5±3.8	36.1±4.0	56.2±3.4	60.1±3.2	65.2±3.2	70.2±4.1	81.2±6.1	93.4±5.1	100	0.0
R. dominica	Adult	62.7±0.0	95.6±3.1	100	100	100	100	100	100	100	0.0
	Egg	36.1±6.0	40.1±2.0	50.2±6.1	63.1±6.1	80.2±4.1	90.4±3.4	96.2±6.1	100	100	0.0
	Larva	35.4±6.7	40.1±4.1	60.4±2.1	70.1±6.7	83.1±5.1	96.4±3.4	100	100	100	0.0
	Pupa	30.4±6.1	36.1±5.6	50.2±6.1	56.1±3.2	63.6±1.9	67.1±2.1	80.2±1.4	90.4±3.4	100	0.0
T. castaneum	Adult	50.0±0.0	92.7±3.1	100	100	100	100	100	100	100	0.0
	Egg	30.1±2.4	50.0±0.0	85.0±1.9	94.5±2.3	100	100	100	100	100	0.0
	Larva	74.5±2.3	84.6±3.1	100	100	100	100	100	100	100	0.0
	Pupa	60.0±1.9	73.4±6.1	90.3±4.1	100	100	100	100	100	100	0.0
T. granarium larvae	Active	0.0	3.3±0.0	19.8±0.0	39.6±0.0	72.6±0.0	85.8±0.0	95.4±3.1	100	100	0.0
	diapause	0.0	0.0	9.9±0.0	26.4±1.1	66.0±0.0	82.5±0.0	92.4±2.0	96.4±3.1	100	0.0

exposure and reached complete kill after 7 day-exposure period. At 2 day-exposure, the percentage mortalities of egg, larva and pupa were 28.2 ± 3.1, 30.6 ± 3.4 and 26.1 ± 6.1%, respectively. These values increased to 100% at 50, 42 and 50 day-exposure, respectively. Accordingly, the exposure time for achieving complete kill for the various stages of ***S. oryzae*** using CA of 60 ± 5% CO_2 at 18 ± 2°C inside the closed fiberglass bins was at least 7 weeks.

R. dominica:

Percentage mortality of the adult of ***R. dominica*** at 2 day-exposure was 30.2 ± 3.1% and this value increased to complete kill at 14 day-exposure. Egg percentage mortality at 2 day-exposure was 28.6 ± 3.1% and this value reached 100% kill at 50 day-exposure. Larval percentage mortality was 21.2 ± 3.6% at 2 day-exposure and this figure reached complete kill at 42 days post-treatment. Pupal percentage mortality was 25.2 ± 3.1% at 2 day-exposure and this value increased gradually to reach 100% at 50 day-exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominica,*** the necessary exposure time was at least 7 weeks.

T. castaneum:

At 2 day-exposure, percentage mortalities of the adult, egg, larva and pupa of ***T. castaneum*** were 45.6 ± 3.1, 25.2 ± 3.4, 40.1 ± 2.1 and 36.2 ± 6.1%, respectively. In case of the adult and larval stages, complete kill was recorded after 7 days of exposure, while in case of egg complete kill was recorded after 21 day-exposure, while in case of pupa complete mortalities were recorded at 14 day-exposure. The exposure time for achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions was at

least 3 weeks.

T. granarium:

At 2 day-exposure nil percentage mortalities were recorded for the active and diapausing larvae of ***T. granarium,*** but these values increased with the increase of the exposure time to reach 100% mortality at 42 and 50 day-exposure for the active and diapause larvae, respectively. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 7 weeks.

In summary, the results showed clearly, that an exposure period of at least 7 weeks is necessary to achieve total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using CA of 60 ± 5% CO_2 inside the closed fiberglass bins at grain temperature of 18 ± 2°C.

3c- Efficacy of CA of 60 ± 5% CO_2 against the tested insect species at 18 ± 2°C, 55 ± 5% R.H. inside the closed metal drums at varying exposure periods:

The obtained results are presented in Table 4c. The results show that mortality values increased with increasing the exposure period.

S. oryzae:

For the adult of ***S. oryzae*** mortality value was 90.2 ± 2.1 and 100% at 3 and 7 day-exposure, respectively. Egg percentage mortality was 36.2 ± 2.1% at 3 day-exposure and this value increased gradually to reach 100% at 42 day-exposure period. Larval percentage mortality was 40.1 ± 3.1% at 3 day-exposure

Table (4b): Responses of the tested stages of various insect species to CA of 60 ± 5 % CO_2 in the closed fiberglass bins at 18 ± 2 °C, 55 ± 5% R.H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)										Contr
		2	3	5	7	14	21	28	35	42	50	
S. oryzae	Adult	40.1±6.1	71.6±3.2	92.4±3.0	100	100	100	100	100	100	100	0.0
	Egg	28.2±3.1	30.1±2.1	35.3±3.1	43.1±3.0	57.1±3.2	70.1±4.1	78.7±1.9	90.1±2.1	98.2±3.1	100	0.0
	Larva	30.6±3.4	34.2±2.0	39.2±6.1	53.6±3.2	63.6±3.2	72.1±4.6	88.0±0.0	97.1±4.2	100	100	0.0
	Pupa	26.1±6.1	28.7±6.1	33.1±3.0	45.1±2.3	55.1±2.3	63.1±3.2	70.3±6.1	88.1±2.4	95.3±4.1	100	0.0
R. dominica	Adult	30.2±3.1	50.6±3.1	80.1±3.2	96.4±5.1	100	100	100	100	100	100	0.0
	Egg	28.6±3.1	33.1±4.2	38.4±3.4	41.8±3.4	51.8±3.4	69.5±3.4	76.2±6.2	85.2±3.1	95.1±3.1	100	0.0
	Larva	21.2±3.6	28.3±3.6	36.1±3.1	50.3±6.1	60.3±6.1	66.1±2.6	82.0±0.0	94.1±3.4	100	100	0.0
	Pupa	25.2±3.1	27.6±1.6	30.1±3.6	50.2±3.1	70.2±3.1	75.2±3.6	80.1±1.2	88.1±2.1	93.1±2.1	100	0.0
T. castaneum	Adult	45.6±3.1	70.2±6.1	83.6±2.1	100	100	100	100	100	100	100	0.0
	Egg	25.2±3.4	40.2±6.1	71.6±3.1	80.7±2.1	95.7±2.1	100	100	100	100	100	0.0
	Larva	40.1±2.1	70.6±3.1	90.1±2.4	100	100	100	100	100	100	100	0.0
	Pupa	36.2±6.1	62.6±3.1	76.2±4.1	88.3±2.6	100	100	100	100	100	100	0.0
T. granarium larvae	Active	0.0	0.0	16.5±2.1	29.5±6.2	39.5±6.2	52.6±3.4	72.4±3.0	95.6±3.4	100	100	0.0
	diapause	0.0	0.0	3.3±0.0	12.9±1.6	22.9±1.6	39.3±3.1	55.8±3.1	77.4±3.1	88.6±2.1	100	0.0

and this value raised to 88.4 ± 3.2% after 21 days from treatment and reached complete kill after 35 day-exposure. Pupal percentage mortality reached 35.2 ± 3.1% at 3 day-exposure period and raised to 80.2 ± 3.4% after 21 day-exposure and this value was 100% kill at 42 day-exposure. The exposure time required for achieving complete kill for the various stages of ***S. oryzae*** using CA of 60 ± 5% CO_2 at 18 ± 2°C inside the closed metal drums was at least 6 weeks.

R. dominica:

Percentage mortality of the adult of ***R. dominica*** was 83.2 ± 3.1% at 3 day-exposure and this value reached 100% mortality after 7 days of exposure. Egg percentage mortality at 3 day-exposure was 40.3 ± 4.1% and this value increased to complete kill at 42 day-exposure. Larval percentage mortality at 3 day-exposure was 33.1 ± 6.1% and this value raised to 100% at 35 day-exposure. Pupal percentage mortality was 30.2 ± 6.1% at 3 day-exposure and this value increased to reach 100% at 42 day-exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominica,*** the exposure time was at least 6 weeks.

T. castaneum:

Adult percentage mortality of ***T. castaneum*** was 46.3 ± 6.1% at 3 day-exposure and this value increased to 100% at 7 day-exposure. Egg percentage mortality was 45.2 ± 3.1% at 3 day-exposure and reached complete kill after 10 day-exposure. Larval percentage mortality was 77.2 ± 4.1% at 3 day-exposure and 100% kill was achieved at 7 day post-treatment. Pupal percentage mortality was 70.1 ± 4.2% at 3 day-exposure and this value reached 100% at 7 day-exposure. The exposure time for

achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions was less than 2 weeks.

T. granarium:

No mortalities recorded for the active and diapausing larvae of ***T. granarium*** at 3 day-exposure. These values increased to complete mortality at 35 and 42 day post-treatment for the active and diapausing larvae, respectively. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 8 weeks.

Briefly, the results showed clearly, that an exposure period of at least 6 weeks is needed to obtain total extinction of the population of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using CA of 60 ± 5% CO_2 inside the closed metal drums at grain temperature of 18 ± 2°C.

4- Efficacy of CA of 60% CO_2 against the tested insect species at 28 ± 2°C and 55 ± 5% R.H. inside the various storage facilities:

4a- Efficacy of CA of 60 ± 5% CO_2 against the tested insect species at 28 ± 2°C, 55 ± 5% R.H. inside the closed steel bins at varying exposure periods:

The results are presented in Table 5a. The results show clearly that mortalities of the various insects and their immature stages were increased with rising the exposure period.

S. oryzae:

Adult percentage mortality of ***S. oryzae*** was 92.4 ± 0.0% at 2 day-exposure and reached complete kill after 3 day-exposure

Table (4c): Responses of the tested stages of various insect species to CA of 60 ± 5 % CO_2 in the closed metal drums at 18 ± 2°C, 55 ± 5% R.H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)								Control
		3	7	10	14	21	28	35	42	
S. oryzae	Adult	90.2±2.1	100	100	100	100	100	100	100	0.0
	Egg	36.2±2.1	55.3±2.2	63.3±4.1	77.3±4.2	85.3±2.6	93.2±6.1	99.2±4.1	100	0.0
	Larva	40.1±3.1	60.2±4.2	70.2±3.4	80.3±2.1	88.4±3.2	97.2±3.2	100	100	0.0
	Pupa	35.2±3.1	50.2±6.1	60.2±3.2	73.1±6.2	80.2±3.4	90.3±4.1	95.2±6.1	100	0.0
R. dominica	Adult	83.2±3.1	100	100	100	100	100	100	100	0.0
	Egg	40.3±4.1	53.2±1.2	62.4±2.3	73.4±6.1	80.3±4.2	90.2±6.1	97.2±4.1	100	0.0
	Larva	33.1±6.1	58.2±6.1	68.3±2.1	77.1±6.1	83.2±4.1	93.2±4.2	100	100	0.0
	Pupa	30.2±6.1	46.3±2.1	55.3±6.2	70.2±4.1	76.2±3.2	83.1±4.2	91.2±6.1	100	0.0
T. castaneum	Adult	46.3±6.1	100	100	100	100	100	100	100	0.0
	Egg	45.2±3.1	85.2±3.2	100	100	100	100	100	100	0.0
	Larva	77.2±4.1	100	100	100	100	100	100	100	0.0
	Pupa	70.1±4.2	100	100	100	100	100	100	100	0.0
T. granarium larvae	Active	0.0	30.3±0.0	66.3±2.1	80.3±4.1	88.3±2.1	96.2±4.1	100	100	0.0
	diapause	0.0	20.1±2.1	53.1±4.2	70.2±6.1	80.3±2.1	88.2±4.1	96.2±4.1	100	0.0

period. Egg percentage mortality was 40.2 ± 4.1 at 2 day-exposure and reached 100% after 3 weeks from treatment. Larval percentage mortality was 43.4 ± 2.1% at 2 day-exposure and 100% kill was achieved at 2 week-exposure. Pupal percentage mortality was 44.2 ± 6.1% at 2 day-exposure and this value reached 100% kill at 4 week post-treatment. The exposure time required for achieving 100% mortalities for the various stages of *S. oryzae* using CA of 60 + 5% CO_2 at 28 + 2°C inside the closed steel bins, was at least 4 weeks.

R. dominica:

Adult percentage mortality of ***R. dominica*** was 75.9 ± 0.0% at 2 day-exposure and this value reached 100% mortality at 3 day-exposure period. Egg percentage mortality was 36.1 ± 3.0% at 2 day-exposure and reached complete kill after 3 weeks from treatment. Larval percentage mortality was 40.2 ± 1.1% at 2 day-exposure and complete kill was achieved at 3 week-exposure. Pupal percentage mortality was 36.1 ± 3.0% at 2 day-exposure and this percentage was 100% at 4 week-exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominica,*** the necessary exposure time was at least 4 weeks.

T. castaneum:

Adult mortality of ***T. castaneum*** was 66.0 ± 0.0% at 2 day-exposure and this value reached rapidly 100% kill at 3 day-exposure period. Egg mortality was 36.3 ± 4.3% at 2 day-exposure and this value reached 100% kill at 7 day-exposure period. Larval mortality was 84.4 ± 2.3% at 2 day-exposure and this value reached 100% kill at 5 day-exposure. Pupal mortality was 70.4 + 6.1% at 2 day-exposure and this percentage reached complete kill after 5 day post-treatment. The results showed also

that the exposure time needed to achieve complete mortalities for the various stages of ***T. castaneum*** using the above condition was found to be at least one week.

T. granarium:

Percentage mortalities obtained for the active and diapausing larvae of ***T. granarium*** at 2 day-exposure were 3.3 ± 0.0 and 0.0%, respectively. These values increased to 100% at 3 and 4 week-exposure for the active and diapausing larvae, respectively. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 4 weeks.

In summary, the results showed clearly, that an exposure period of at least 4 weeks is necessary to achieve total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using CA of 60 ± 5% CO_2 inside the closed steel bins at grain temperature of 28 ± 2°C.

4b- Efficacy of CA of 60 ± 5% CO_2 against the tested insect species at 28 ± 2°C, 55 ± 5% R.H. inside the closed fiberglass bins at varying exposure periods:

The obtained results are presented in Table 5b. The results show that mortality values of the various insects and their developmental stages increased with increasing the exposure period.

S. oryzae:

Adult percentage mortality of ***S. oryzae*** was 50.1 ± 3.1% at 2 day-exposure and this value reached 100% at 7 day-exposure

Table (5a): Responses of the tested stages of various insect species to CA of 60 ± 5 % CO_2 in the closed steel bins at 28 ± 2 °C, 55 ± 5% R.H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)								Contr
		2	3	5	7	10	14	21	28	
S. oryzae	Adult	92.4±0.0	100	100	100	100	100	100	100	0.0
	Egg	40.2±4.1	58.2±6.1	70.1±3.4	83.6±4.0	92.1±5.0	97.2±1.9	100	100	0.0
	Larva	43.4±2.1	60.1±0.0	66.2±4.6	85.1±3.0	96.1±7.1	100	100	100	0.0
	Pupa	44.2±6.1	50.2±3.1	70.1±4.2	77.2±3.6	83.4±1.4	92.1±5.0	99.3±2.6	100	0.0
R. dominica	Adult	75.9±0.0	100	100	100	100	100	100	100	0.0
	Egg	36.1±3.0	50.2±6.0	68.1±4.1	77.2±3.4	88.1±6.0	95.2±5.0	100	100	0.0
	Larva	40.2±1.1	47.0±9.0	73.1±4.6	86.4±5.0	93.2±4.1	100	100	100	0.0
	Pupa	36.1±3.0	44.4±3.1	66.1±6.0	73.4±6.3	83.4±2.1	93.1±7.0	97.3±4.1	100	0.0
T. castaneum	Adult	66.0±0.0	100	100	100	100	100	100	100	0.0
	Egg	36.3±4.6	79.2±4.6	94.5±2.3	100	100	100	100	100	0.0
	Larva	84.4±2.3	95.6±3.2	100	100	100	100	100	100	0.0
	Pupa	70.4±6.1	90.4±3.4	100	100	100	100	100	100	0.0
T. granarium larvae	Active	3.3±0.0	23.1±1.1	42.9±3.0	75.9±4.6	84.9±10.9	97.3±2.1	100	100	10.0
	diapause	0.0	16.5±0.0	33.0±0.0	66.0±0.0	75.9±0.0	88.4±2.6	96.4±2.1	100	0.0

period. Egg mortality was 33.2 ± 3.1% at 2 day-exposure and this value reached 100% kill at 35 day-exposure. Larval mortality was 36.3 ± 4.1% at 2 day-exposure and this value reached 100% kill at 35 day-exposure. Pupal mortality was 30.3 ± 4.3% at 2 day-exposure and this percentage reached complete kill after 42 days exposure period. Accordingly, the exposure time needed for achieving complete mortalities for the various stages of ***S. oryzae*** using CA of 60 ± 5% CO_2 at 28 ± 2°C inside the closed fiberglass bins was at least 6 weeks. Also the pupal stage was the most resistant, while the adult was the most sensitive.

R. dominica:

Adult percentage mortality of ***R. dominica*** was 43.1 ± 2.6% at 2 day-exposure and this value raised to 77.3 ± 2.6% at 3 day-exposure and reached complete mortality after 7 day post-treatment. Egg percentage mortality was 30.1 ± 4.1% at 2 day-exposure and reached 100% after 42 day-exposure. Larval percentage mortality was 32.6 ± 2.1% at 2 day exposure and 100% kill was achieved at 35 day-exposure. Pupal percentage mortality was 30.0 ± 0.0% at 2 day-exposure and complete kill was reached at 42 day-exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominica,*** the necessary exposure time was at least 6 weeks. Pupae and eggs were more resistant to CO_2 than larvae and adults of ***R. dominica***.

T. castaneum:

Adult percentage mortality of ***T. castaneum*** was 51.1 ± 2.1% at 2 day-exposure and this value increased to 100% at 7 day-exposure. Egg percentage mortality was 30.3 ± 6.1% at 2 day-exposure and reached complete kill after 14 day-exposure. Larval percentage mortality was 46.1 ± 2.1% at 2 day-exposure

and 100% kill was achieved at 7 day post-treatment. Pupal percentage mortality was 44.2 ± 2.1% at 2 day-exposure and this value reached 100% at 7 day-exposure. The exposure time for achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions was found to be at least 2 weeks.

T. granarium:

No mortalities recorded for the active and diapausing larvae of ***T. granarium*** at 2 day-exposure. These values increased to complete mortality at 35 and 42 day post-treatment for the active and diapausing larvae, respectively. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 6 weeks.

Briefly, the results showed clearly, that an exposure period of at least 6 weeks is needed to obtain total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using CA of 60 ± 5% CO_2 inside the closed fiberglass bins at grain temperature of 28 ± 2°C.

4c- Efficacy of CA of 60 ± 5% CO_2 against the tested insect species at 28 ± 2°C, 55 ± 5% R.H. inside the closed metal drums at varying exposure periods:

The obtained results are presented in Table 5c. The results show that mortality values of the various insects and their developmental stages increased with increasing the exposure period.

S. oryzae:

For the adult of ***S. oryzae*** mortality value was 80.2 ± 3.1

Table (5b): Responses of the tested stages of various insect species to CA of 60 ± 5 % CO_2 in the closed fiberglass bins at 28 ± 2 °C, 55 ± 5% R.H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)									Control
		2	3	5	7	14	21	28	35	42	
S. oryzae	Adult	50.1±3.1	83.4±6.1	98.2±3.1	100	100	100	100	100	100	0.0
	Egg	33.2±3.1	40.3±2.1	46.2±3.2	56.1±3.4	66.1±3.1	77.2±3.4	85.2±6.1	100	100	0.0
	Larva	36.3±4.1	45.2±3.1	55.3±6.1	69.4±4.1	70.3±2.4	83.2±5.0	99.2±3.1	100	100	0.0
	Pupa	30.3±4.3	36.3±2.1	44.3±3.4	50.1±3.1	65.6±4.2	73.3±4.1	81.1±3.2	97.2±6.1	100	0.0
R. dominica	Adult	43.1±2.6	77.3±2.6	90.1±2.4	100	100	100	100	100	100	0.0
	Egg	30.1±4.1	36.2±3.2	42.6±4.2	55.1±3.2	63.3±4.1	75.1±1.2	80.1±3.1	98.2±6.1	100	0.0
	Larva	32.6±2.1	40.3±4.1	46.3±4.1	55.1±3.2	69.3±4.1	76.2±4.1	93.2±4.2	100	100	0.0
	Pupa	30.0±0.0	33.1±2.1	40.3±3.1	46.3±4.1	61.3±2.1	81.2±3.4	90.3±2.1	95.4±3.4	100	0.0
T. castaneum	Adult	51.1±2.1	66.3±3.1	80.1±3.1	100	100	100	100	100	100	0.0
	Egg	30.3±6.1	48.2±3.1	66.1±4.1	95.2±3.4	100	100	100	100	100	0.0
	Larva	46.1±2.1	77.3±3.1	95.2±3.4	100	100	100	100	100	100	0.0
	Pupa	44.2±2.1	73.1±4.2	92.3±4.2	100	100	100	100	100	100	0.0
T. granarium larvae	Active	0.0	15.6±2.4	30.1±4.2	50.2±2.1	66.3±4.1	75.3±3.2	95.4±3.1	100	100	0.0
	diapause	0.0	3.3±3.1	16.4±2.1	39.6±3.2	46.1±4.1	62.3±2.1	85.1±4.1	97.2±6.2	100	0.0

and 100% at 2 and 3 day-exposure, respectively. Egg percentage mortality was 36.2 ± 3.1% at 2 day-exposure and this value increased gradually to reach 100% at 28day-exposure period. Larval percentage motility was 40.2 ± 1.6% at 2 day-exposure and this value raised to 76.1 ± 1.6% at 7 days from treatment and reach complete kill after 21 day-exposure. Pupal percentage mortality reach 35.1 ± 2.6% at 2 day-exposure period and raised to 58.3 ± 3.4% after 7 day-exposure and this value reached 100% kill at 35 days post-treatment. Consequently, the exposure time for achieving complete kill for the various stages of ***S. oryzae*** using CA of 60 ±5% CO_2 at 28 ± 2°C inside the closed metal drums was at least 5 weeks.

R. dominica:

Percentage mortality of the adult of ***R. dominica*** at 2 day-exposure was 60.3 ± 2.1% and this value increased to complete kill at 5 day-exposure. Egg percentage mortality at 2 day-exposure was 35.2 ± 3.1% and this value reached 100% kill at 28 day-exposure. Larval percentage mortality was 38.3 ± 2.4% at 2 day-exposure and this figure reached complete kill at 28 days post-treatment. Pupal percentage mortality was 35.1 ± 1.2% at 2 day-exposure and this value increased gradually to reach 100% at 35 day-exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominica,*** the required exposure time was at least 5 weeks.

T. castaneum:

At 2 day-exposure, percentage mortalities of the adult, egg, larva and pupa of ***T. castaneum*** were 55.7 ± 3.4, 30.2 ± 4.1, 70.4 ± 6.1 and 60.2 ± 3.4%, respectively. In case of the adult stages, complete kill was recorded after 5 days of exposure, in case of

egg stages complete kill was recorded after 10 day-exposure, while in case of larval and pupal stages complete kill were recorded after 7 day-exposure. The exposure time for achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions was less than 2 weeks.

T. granarium:

Percentage mortalities obtained for the active and diapausing larvae of ***T. granarium*** at 2 day-exposure were 3.3 ± 0.0 and 0.0, respectively. But these values increased with the increase of the exposure time to reach 100% mortality at 28 and 35 day-exposure for the active and diapause larvae, respectively. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 5 weeks.

In conclusion, the results showed clearly, that an exposure period of at least 6 weeks is necessary to obtain total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using CA of 60 ± 5% CO_2 inside the closed metal drums at grain temperature of 28 ± 2°C.

-Loss of 60% CO_2 concentrations inside the various storage facilities at different exposure periods during summer and winter times:

Table (6a) & fig (8) showed the loss of CO_2 concentrations inside the different storage facilities at winter times. And the Table (6b) & fig (9) showed the loss of CO_2 concentrations inside the different storage facilities at summer times.

Table (5c): Responses of the tested stages of various insect species to CA of 60 ± 5 % CO_2 in the closed metal drums at 28 ± 2°C; 55 ± 5% R.H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)									Control
		2	3	5	7	10	14	21	28	35	
S. oryzae	Adult	80.2±3.1	100	100	100	100	100	100	100	100	0.0
	Egg	36.2±3.1	46.2±3.4	58.2±6.1	61.2±2.1	71.3±4.2	80.2±6.1	93.2±4.2	100	100	0.0
	Larva	40.2±1.6	50.3±1.6	60.1±1.4	76.1±1.6	83.4±2.5	90.2±3.4	100	100	100	0.0
	Pupa	35.1±2.6	44.3±6.1	53.2±2.6	58.3±3.4	70.3±2.4	79.3±3.1	81.2±6.1	97.2±3.1	100	0.0
R. dominica	Adult	60.3±2.1	93.4±6.1	100	100	100	100	100	100	100	0.0
	Egg	35.2±3.1	44.3±2.3	55.3±6.1	60.3±2.1	70.2±3.1	81.3±2.4	95.3±2.1	100	100	0.0
	Larva	38.3±2.4	51.3±2.6	63.2±2.6	75.2±2.3	80.2±1.6	88.3±2.6	97.3±2.6	100	100	0.0
	Pupa	35.1±1.2	40.2±1.6	50.2±3.1	56.3±4.1	66.3±2.1	77.2±3.1	88.3±2.4	95.2±3.1	100	0.0
T. castaneum	Adult	55.7±3.4	90.2±6.1	100	100	100	100	100	100	100	0.0
	Egg	30.2±4.1	60.6±3.2	80.2±3.1	97.4±3.1	100	100	100	100	100	0.0
	Larva	70.4±6.1	81.3±2.4	97.3±4.1	100	100	100	100	100	100	0.0
	Pupa	60.2±3.4	78.4±3.2	91.4±3.2	100	100	100	100	100	100	0.0
T. granarium larvae	Active	3.3±0.0	16.2±6.1	36.4±2.1	55.3±2.4	70.3±4.2	80.2±3.4	91.2±3.4	100	100	0.0
	diapause	0.0	9.6±3.1	30.2±4.2	50.2±3.1	66.3±4.2	73.6±2.4	83.2±4.6	93.2±4.1	100	0.0

Table (6a): Concentrations of 60% CO_2 inside the various storage facilities at different exposure periods during winter times.

Storage facilities	CO_2 concentration at various exposure periods (days)					
	3	7	14	21	28	35
Closed steel bins	60	60	60	59	59	58
Closed fiberglass bins	60	55	45	35	30	28
Closed metal drums	60	60	59	58	57	56

Table (6b): Concentrations of 60% CO_2 inside the various storage facilities at different exposure periods during summer times.

Storage facilities	CO_2 concentration at various exposure periods (days)				
	3	7	14	21	28
Closed steel bins	60	60	59	58	57
Closed fiberglass bins	60	55	49	38	27
Closed metal drums	60	59	57	56	55

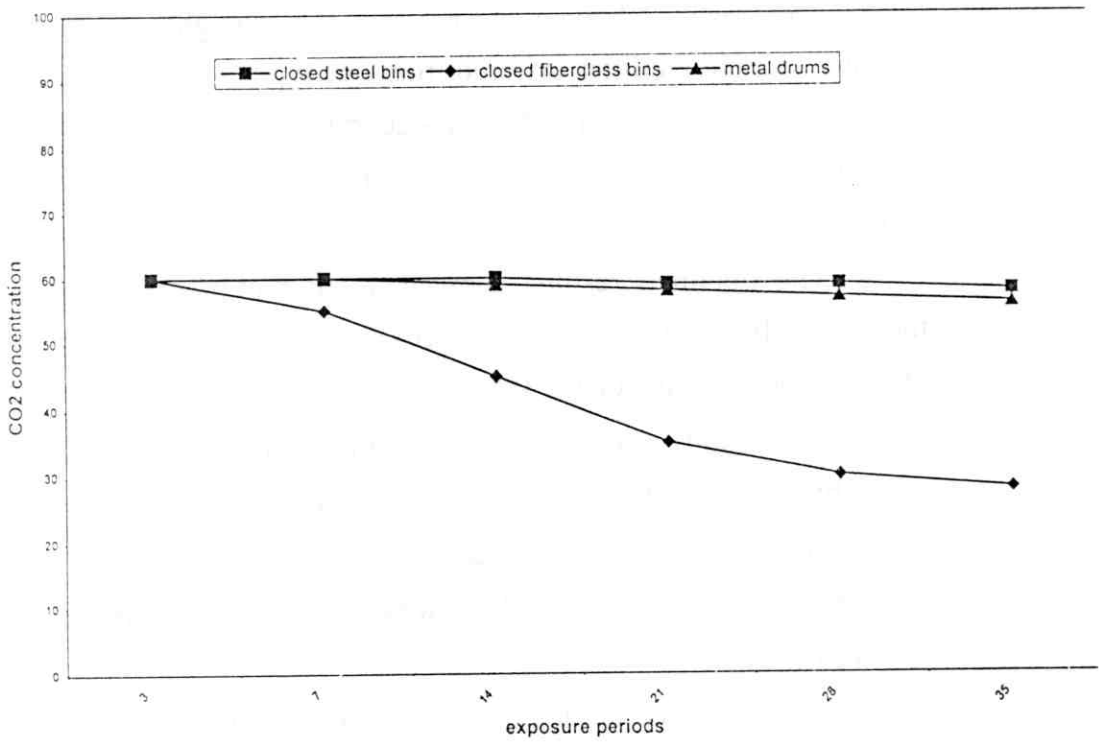

Fig (6): Concentrations of 60% CO_2 inside the different storage facilities at winter times.

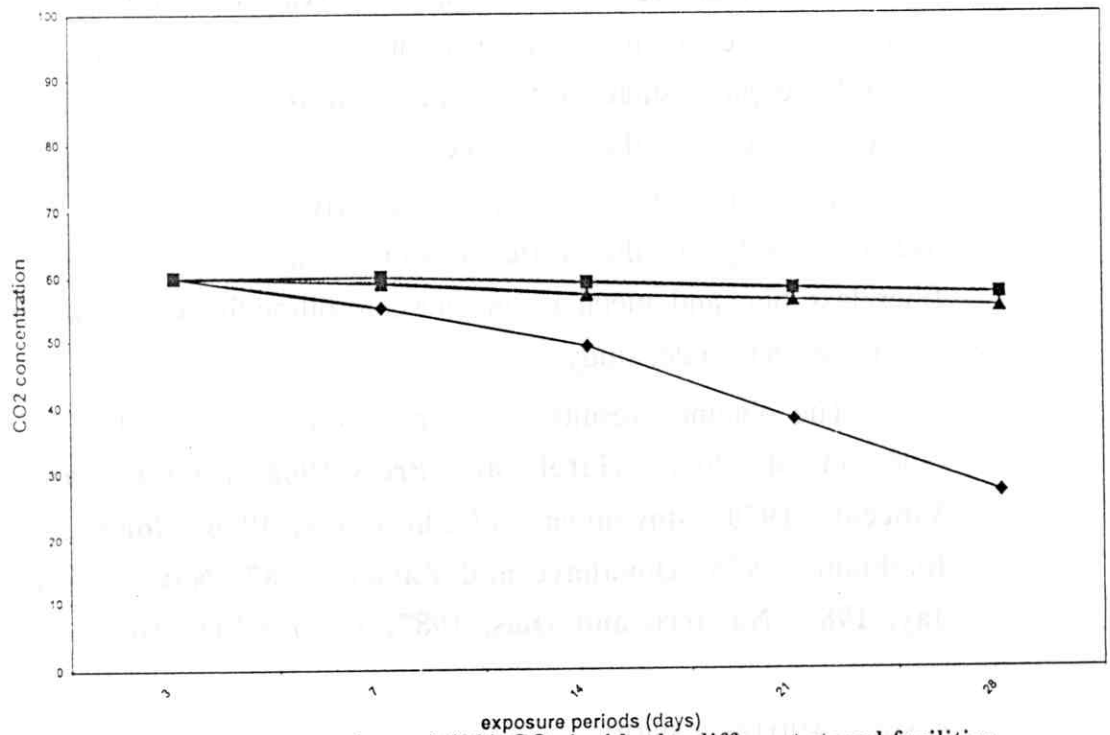

Fig (7): Concentrations of 60% CO_2 inside the different stored facilities at summer times.

The results showed clearly that the gastightness of the various storage facilities differed from one type to another. At the same time, it was very high for the steel bins and was very low for the fiber glass bin, while it was moderate for the closed metal drums.

The obtained results showed clearly that mortality values increased by extending the exposure time and with increasing the grain temperature inside the storage facility.

The results revealed also, that the higher the gastightness of the bin, the higher the insect mortality was.

Increasing the temperature of the grains and the concentration of CO_2 inside the storage bins resulted in higher insect mortality.

Insects varied in their susceptibility to the CA of CO_2. The immature stages of various insects were more tolerant to the CA of CO_2 than the adult stages. ***Trogoderma granarium*** diapausing larvae were more resistant than active larvae. CA of CO_2 was more effective at higher temperature than the lower one. In general the pupal stages of ***S. oryzae*** and ***R. dominica*** were more resistant of CO_2 than the adult stage.

The obtained results indicate clearly that CA of CO_2 can use effectively in the different storage facilities (steel bins, fiberglass bin, and metal drum) for controlling the tested stored product insects under study.

The obtained results are in harmony with the findings of other investigators. **(Harein and Press 1968; Lindgren and Vincent, 1970; Stoyanova and Shikrenov, 1976; Bond and Buckland, 1978; Donahaye and Zalach, 1987; Navarro and Jay, 1987; Navarro and Dias, 1987; Fleurat-Lessard *et al.*,**

1991, Ofuya and Reichmuth, 1993 and El-Lakwah *et al.*, 1991 a & b, 1994, 1997 and 1998).

Banks and Sharp (1979) conducted a trial using CO_2 for the treatment of wheat and rye. They used about 60% CO_2 generated from dry ice under plastic sheeting at 11 to 13°C. The CO_2 level was maintained for 22 days. The pest infestation was predominately ***R. dominica*** with small numbers of ***T. castaneum, S. oryzae, Ephestia caulella*** and ***Cryptolestes ferrugineus.*** Small numbers of ***R. dominica*** only survived the treatment, emerging as adults four weeks or more after the start of incubation, they were presumably early in star larvae at the time of gassing. **Navarro and Jay** (1987) studied the response of the developmental stages of ***S. oryzae, Oryzaephilus surinamensis*** and ***T. castaneum*** to different CAs at temperatures from 15 - 32°C. They found that, the pupae of all species and the larvae of **S. *oryzae*** were less susceptible than eggs and adults to the tested CAs. Exposure to 60% CO_2 for 120 h. at 27°C was sufficient to cause 100% mortality of all stages of the three species. **El-Lakwah *et al.* (1992)** evaluated in the laboratory at 26 ± 1°C and 6 ± 1°C the efficacy of different CO_2 concentrations in CA against ***S. oryzae, R. dominica*** and ***Callosobruchus maculatus.*** The results indicated that CO_2 was more effective at higher temperature and the mortality of adults was increased generally as the concentration was increased. **Hashem and Reichmuth (1992)** pointed out that adults of ***Prostephanus truncatus*** were more tolerant to various tested CA than the adults of ***R. dominica.*** Meanwhile, the adults were more tolerant at 20°C than at 30°C. **Newton *et al.* (1993)** reported that mixed stage cultures of ***Sitophilus oryzae, Tribolium castaneum, Liposcelis***

bostrychophila, Tyrophagus putrescentiae and ***Acarus siro*** were placed inside, between and under 32 kg. sacks in a 1 tone stack of bagged flour and exposed to 60% carbon dioxide in a fumigation "bubble" for 4, 7 or 14 days at about 20°C. ***T. putrescentiae*** survived 14 days exposure. Complete control of ***T. castaneum*** required 7 days exposure; ***S. oryzae, L. bostrychophila*** and ***A. siro*** required 14 days. Burial within the flour stack apparently did not significantly impede the penetration of carbon dioxide to the buried cultures. The flour stack was preheated by circulating warm air (22–29°C) around it. The temperature inside a bag in the lower part of the stack took 120 hours to rise from 11°C to 20°C. Free air space temperature near the stack centre responded similarly. **Whit *et al.* (1995)** determined the effect of concentration of carbon dioxide (CO_2) that can be produced by biological respiration (7.5-19.2%) on oviposition of adults of ***Tribolium castaneum, Cryptolestes pusilus*** or ***C. ferrugineus.*** Results showed that relative to controls, ***T. castaneum, C. pusillus*** and ***C. ferrugineus,*** exposed to 7.5% CO_2 for 1 week, had numbers of offspring reduced by 43, 94 and 50%, respectively, and the total population at 6 weeks was reduced by 53, 84 and 19%, respectively. With levels of 17.1% CO_2 for 1 week, no offspring were produced and exposed adults had high mortality. Eggs and subsequent immature of ***T. confusum, T. castaneum*** and ***C. ferrugineus*** were exposed for 3 weeks to elevated levels of CO_2 at 22°C. Insect development was similar at 7.5 and 8.6% CO_2 with mean mortality 43, 62 and 30% greater than controls for ***T. confusum, T. castaneum*** or ***C. ferrugineus,*** respectively. Also, mean levels of 5.8-8.3% CO2 for 7 weeks reduced, on all sampling dates, populations of ***T. confusum*** by 85%, ***T. castaneum*** by 99%, ***C. pusillus*** by 68% and ***C.***

ferrugineus by 54%. Although ***T. castaneum*** had greater oviposition rate than ***C. pusillus*** at 7.5% CO_2, immature mortality was greater for ***T. castaneum.*** Based on long-term exposure to levels of CO_2 which can be produced by biological activity that affects oviposition and immature development, species in increasing order of sensitivity to CO_2 are ***C. ferrugineus, C. pusillus, T. confusum*** and ***T. castaneum.***

It is known that the gastightness of the fumigation enclosure play an important role on the effectiveness of the used fumigant, the higher the gas tightness of the enclosure the higher the mortality was. Therefore, the high effectiveness of the various treatments inside the closed steel bins revealed that its gastightness was very high. **Reynolds *et al.*, (1967)** mentioned that the slow release of phosphine from the phosphine formulation means that concentration increases slowly at the beginning of the treatment. As it passes a maximum, the concentration decreases even more slowly depending on the gastightness of the structure, absorption of the commodity and wind force on the structure.

5- Efficacy of 100 ppm of phosphine against the tested insect species at 18 ± 2°C and 55 ± 5% R.H. inside the various storage facilities:

5a- Efficacy of 100 ppm of phosphine against the tested insect species at 18 ± 2°C, 55 ± 5% R.H. inside the closed steel bins at varying exposure periods:

The obtained results are presented in Table 7a. The results show clearly that percentage mortalities of the various insects and their developmental stages were increased with rising the exposure period.

Table (7a): Responses of the tested stages of various insect species to 100 ppm of phosphine in the closed steel bins at 18 ± 2°C; 55 ± 5% R. H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)					Control
		1	2	3	5	7	
S. oryzae	Adult	80.1±3.1	100	100	100	100	0.0
	Egg	40.3±2.3	60.2±1.6	80.2±4.1	95.4±1.6	100	0.0
	Larva	46.6±3.1	65.4±2.0	85.1±3.1	100	100	0.0
	Pupa	40.1±2.3	60.0±4.1	83.4±5.1	93.6±4.6	100	0.0
R. dominica	Adult	70.2±3.2	100	100	100	100	0.0
	Egg	36.2±3.2	58.4±4.1	83.6±3.2	93.2±2.1	100	0.0
	Larva	42.4±4.1	63.2±4.1	85.4±6.1	100	100	0.0
	Pupa	40.1±3.2	60.1±4.1	80.6±3.1	90.3±3.1	100	0.0
T. castaneum	Adult	77.3±2.3	100	100	100	100	0.0
	Egg	66.6±0.0	80.2±1.3	97.2±3.1	100	100	0.0
	Larva	80.4±4.1	100	100	100	100	0.0
	Pupa	70.5±1.6	85.4±3.2	100	100	100	0.0
T. granarium larvae	Active	50.5±6.1	80.1±4.2	98.1±6.1	100	100	0.0
	Diapause	43.6±1.6	70.3±2.3	85.4±5.1	100	100	0.0

S. oryzae:

For the adults of ***S. oryzae*** mortality values were 80.1 ± 3.1 and 100% after 1 and 2 day-exposure period, respectively. Egg percentage mortality was 40.3 ± 2.3% at 1 day-exposure and this value increased to reach 100% at 7 day-exposure period. Larval percentage mortality was 46.6 ± 3.1% at 1 day-exposure and this value raised to 85.1 ± 3.1% at 3 days from treatment and reached complete kill after 7 day-exposure. Pupal percentage mortality reached 40.1 ± 2.3% at 1 day-exposure period and raised to 83.4 ± 5.1% after 3 day-exposure and this value was 100% after 5 days post-treatment. Accordingly, the exposure time needed for achieving complete mortalities for the various stages of ***S. oryzae*** using 100 ppm of phosphine at 18 ± 2°C inside the closed steel bins was at least one week. Results showed also that the pupae and eggs of ***S. oryzae*** were less susceptible to Phosphine than the larvae and adults.

R. dominica:

Percentage mortality of the adults of ***R. dominica*** at 1 day-exposure was 70.2 ± 3.2% and this value increased to complete kill at 2 day-exposure. Egg percentage mortality at 1 day-exposure was 36.2 ± 3.2% and this value reached 100% kill at 7 day-exposure. Larval percentage mortality was 42.4 ± 4.1% at 1 day-exposure and this figure reached complete kill at 5 days post-treatment. Pupal percentage mortality was 40.1 ± 3.2% at 1 day-exposure and this value increased gradually to reach 100% at 7 day-exposure. Accordingly, to obtain 100% mortalities for the various stages of ***R. dominica,*** the exposure time needed was at least one week. Also, pupae and eggs of ***R. dominica*** were less susceptible to phosphine than larvae and adults.

T. castaneum:

At 1 day-exposure, percentage mortalities of the adult, egg, larva and pupa of ***T. castaneum*** were 77.3 ± 2.3, 66.6 ± 0.0, 80.4 ± 4.1 and 70.5 ± 1.6%, respectively. In case of the adult and larval stages complete kill was recorded after 2 days of exposure, while in case of egg complete kill were recorded after 5 day-exposure, while in case of pupa complete mortalities were recorded at 3 day-exposure. The exposure time for achieving 100% kill for the various stages of ***T. castaneum*** using the above mentioned treated was at least 5 days. The eggs were the least susceptible to phosphine followed by pupae and adults, while larvae were the most susceptible stage.

T. granarium:

Percentage mortalities obtained for the active and diapausing larvae of ***T. granarium*** at 1 day-exposure were 50.5 ± 6.1 and 43.6 ± 1.6%, respectively. These values increased to 100% at 5 day-exposure for the both larvae. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using phosphine was found to be at least 5 days.

In conclusion, the results showed clearly, that an exposure period of at least one week is necessary to obtain total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using 100 ppm of phosphine inside the closed steel bins at grain temperature of 18 ± 2°C.

5b- Efficacy of 100ppm of phosphine against the tested insect species at 18 ± 2°C, 55 ± 5% R.H. inside the closed fiberglass bins at varying exposure periods:

The obtained results are listed in Table 7b. Clearly, the results shown in this table revealed that percentage mortalities of the various insects and their developmental stages raised gradually with the increase of the exposure period of the insects to PH_3 inside the closed fiberglass bins.

S. oryzae:

At 1 day-exposure, percentage mortalities of the adult, egg, larva and pupa of ***S. oryzae*** were 65.2 ± 3.0, 26.2 ± 2.4, 30.4 ± 2.4 and 27.2 ± 3.2%, respectively. These values increased with the increase of the exposure period to reach complete kill at 2, 10, 10 and 10 day-exposure for the mentioned immature stages, respectively. The exposure time required for achieving complete kill for the various stages of ***S. oryzae*** using 100 ppm of phosphine at 18 ± 2°C inside the closed fiberglass bins was found to be at least 10 days.

R. dominica:

Percentage mortality of the adult of ***R. dominica*** was 56.2 ± 6.1% at 1 day-exposure and this value reached 100% mortality after 3 days of exposure. Egg percentage mortality at 1 day-exposure was 25.6 ± 3.1 % and this value increased to complete kill at 10 day-exposure. Larval percentage mortality at 1 day-exposure was 30.4 ± 3.1% and this value raised to 100% at 7 day-exposure. Pupal percentage mortality was 25.6 ± 3.4 at 1 day-exposure and this value increased to reach 100% at 10 day-exposure. Under this condition, to obtain 100% mortalities for the various stages of ***R. dominica,*** the needed exposure time was at

Table (7b): Responses of the tested stages of various insect species to 100 ppm of phosphine in the closed fiberglass bins at 18 ± 2°C; 55 ± 5% R. H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)						Control
		1	2	3	5	7	10	
S. oryzae	Adult	65.2±3.0	100	100	100	100	100	0.0
	Egg	26.2±2.4	40.3±3.1	61.4±4.1	77.2±3.2	90.3±2.3	100	0.0
	Larva	30.4±2.4	43.4±2.1	64.6±2.6	83.6±2.3	97.4±2.3	100	0.0
	Pupa	27.2±3.2	39.6±4.2	56.4±4.1	75.4±2.3	90.1±4.1	100	0.0
R. dominica	Adult	56.2±6.1	83.4±3.1	100	100	100	100	0.0
	Egg	25.6±3.1	39.6±4.1	58.6±2.0	80.6±1.9	93.4±1.9	100	0.0
	Larva	30.4±3.1	44.6±1.9	60.4±2.0	86.4±1.3	100	100	0.0
	Pupa	25.6±3.4	38.6±2.3	53.2±2.3	75.1±1.3	90.2±4.1	100	0.0
T. castaneum	Adult	60.4±5.3	95.4±1.9	100	100	100	100	0.0
	Egg	43.2±3.2	60.4±3.2	81.2±3.1	100	100	100	0.0
	Larva	60.0±4.1	77.6±3.2	100	100	100	100	0.0
	Pupa	51.0±3.1	70.6±3.2	81.4±4.1	100	100	100	0.0
T. granarium larvae	Active	33.4±3.4	46.4±2.1	73.6±1.9	90.4±3.2	100	100	0.0
	Diapause	28.6±2.0	38.5±2.4	64.2±6.1	83.6±2.3	93.4±1.9	100	0.0

least 10 days.

T. castaneum:

Adult percentage mortality of ***T. castaneum*** was 60.4 ± 5.3% at 1 day-exposure and this value increased to 100% at 3 day-exposure. Egg percentage mortality was 43.2 ± 3.2% at 1 day-exposure and reached complete kill after 5 day-exposure. Larval percentage mortality was 60.0 ± 4.1% at 1 day-exposure and 100% kill was achieved at 3 day post-treatment. Pupal percentage mortality was 51.0 ± 3.1% at 1 day-exposure and this value reached 100% at 5 day-exposure. The exposure time needed for achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions was at least 5 days.

T. granarium:

Percentage mortalities obtained for the active and diapausing larvae of ***T. granarium*** at 1 day-exposure were 33.4 ± 3.4 and 28.6 ± 2.0%, respectively. These values increased to 100% at 7 and 10 week exposure for the active and diapausing larvae, respectively. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 10 days.

In summary, the results showed clearly, that an exposure period of at least 10 days is necessary to achieve total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using 100 ppm of phosphine inside the closed fiberglass bins at grain temperature of 18 ± 2°C.

5c- Efficacy of 100 ppm of phosphine against the tested insect species at 18 ± 2°C, 55 ± 5% R.H. inside the closed metal drums at varying exposure periods:

The obtained results are presented in Table 7c. The results show that mortality values raised with increasing the exposure period.

S. oryzae:

Adult percentage mortality of ***S. oryzae*** was 78.2 ± 1.9% at 1 day-exposure and this value reached complete kill after 2 day-exposure period. At 1 day-exposure, the percentage mortalities of egg, larva and pupa were 38.3 ± 2.3, 40.2 ± 2.3 and 36.1 ± 2.3%, respectively. These values increased to 100% at 7 day-exposure for the above immature stages. Accordingly, the exposure time required for achieving complete kill for the various stages of ***S. oryzae*** using 100 ppm of phosphine at 18 ± 2°C inside the closed metal drums was at least 7 days. These results indicated clearly, that the adult stage was the most susceptible to phosphine.

R. dominica:

Adult percentage mortality of ***R. dominica*** was 68.2 ± 4.1% at 1 day-exposure and this value reached complete kill after 2 day post-treatment. gg ercentage ortality as 5.3 .4% at 1 day-exposure and reached 100% after 7 day-exposure. Larval percentage mortality was 38.2 ± 2.3% at 1 day-exposure and 100% kill was achieved at 7 day-exposure. Pupal percentage mortality was 33.1 ± 6.1% at 1 day-exposure and complete kill at 7 day-exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominica,*** the exposure time needed was at least 7 days, and the immature stages were more tolerant to phosphine than the adult stages.

Table (7c): Responses of the tested stages of various insect species to 100 ppm of phosphine in the closed metal drums at 18 ± 2°C; 55 ± 5% R. H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)					Control
		1	2	3	5	7	
S. oryzae	Adult	78.2±1.9	100	100	100	100	0.0
	Egg	38.3±2.3	58.2±3.1	80.1±1.3	93.2±1.3	100	0.0
	Larva	40.2±2.3	63.4±2.0	83.3±2.3	99.1±1.4	100	0.0
	Pupa	36.1±2.3	56.2±1.9	80.2±2.3	90.2±2.0	100	0.0
R. dominica	Adult	68.2±4.1	100	100	100	100	0.0
	Egg	35.3±1.4	55.1±1.9	80.2±1.4	90.2±2.0	100	0.0
	Larva	38.2±2.3	60.3±3.2	52.1±5.1	98.2±5.1	100	0.0
	Pupa	33.1±6.1	53.2±3.2	78.3±2.3	88.1±6.1	100	0.0
T. castaneum	Adult	75.3±2.3	100	100	100	100	0.0
	Egg	63.1±1.9	78.3±1.3	95.1±1.3	100	100	0.0
	Larva	77.4±4.1	100	100	100	100	0.0
	Pupa	68.2±3.2	83.4±1.3	100	100	100	0.0
T. granarium larvae	Active	46.3±5.3	77.4±2.3	95.1±6.1	100	100	0.0
	Diapause	40.2±1.3	70.3±1.3	82.3±4.1	100	100	0.0

T. castaneum:

The obtained percentage mortalities at 1 day-exposure were 75.3 ± 2.3, 63.1 + 1.9, 77.4 ± 4.1 and 68.2 + 3.2% for the adult, egg, larva and pupa of ***T. castaneum,*** respectively. Complete mortalities were obtained at 2 day-exposure for the adult and larval stages and 5 day-exposure for the egg while 2 day-exposure in case of pupal stages. The exposure time for achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions was accordingly at least 5 days. Also, the pupal and egg stages of ***T. castaneum*** were more tolerant to phosphine than the adult and larval stages.

T. granarium:

Percentage mortalities obtained for the active and diapausing larvae of ***T. granarium*** at 1 day-exposure were 46.3 ± 5.3 and 40.2 ± 1.3%, respectively. These values increased to 100% at 5 day-exposure for the both larvae. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 5 days.

Briefly, the results showed clearly, that an exposure period of at least one week is needed to obtain total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using 100 ppm of phosphine inside the closed metal drums at grain temperature of 18 ± 2°C.

6- Efficacy of 100 ppm of phosphine against the tested insect species at 28 ± 2°C and 55 ± 5% R.H. in the various storage facilities:

6a- Efficacy of 100 ppm of phosphine against the tested insect species at 28 ± 2°C, 55 ± 5% R.H. inside the closed steel bins at varying exposure periods:

The obtained results are given in Table 8a. The results show clearly that percentage mortalities of the various insects and their immature stages were increased by extending the time of exposure.

S. oryzae:

At 1 day-exposure, percentage mortalities of the adult, egg, larva and pupa of ***S. oryzae*** were 85.1 ± 3.1, 50.2 ± 3.1, 60.3 ± 3.2 and 50.1 ± 4.1%, respectively. These values increased with the increase of the exposure period to reach complete kill at 2, 3, 3 and 5 day-exposure for the mentioned immature stage, respectively. The exposure time required for achieving complete kill for the various stages of ***S. oryzae*** using 100 ppm of PH_3 at 28 ± 2°C inside the closed steel bins was at least 5 days. Meanwhile, the pupal stage of ***S. oryzae*** was the most tolerant followed by egg and larva, while, the adult was the most susceptible stage.

R. dominica:

Adult percentage mortality of ***R. dominica*** was 83.4 ± 3.2% at 1 day-exposure and this value reached complete mortality after 2 day post-treatment. Egg percentage mortality was 46.3 ± 2.3% at 1 day-exposure and reached 100% after 5 day-exposure. Larval percentage mortality was 53.2 ± 2.3% at 1 day-exposure and 100% kill was achieved at 5 day-exposure. Pupal percentage

Table (8a): Responses of the tested stages of various insect species to 100 ppm of phosphine in the closed steel bins at 28 ± 2°C; 55 ± 5% R. H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)				Control
		1	2	3	5	
S. oryzae	Adult	85.1±3.1	100	100	100	0.0
	Egg	50.2±3.1	80.1±2.3	100	100	0.0
	Larva	60.3±3.2	85.6±6.1	100	100	0.0
	Pupa	50.1±4.1	78.4±2.3	98.1±2.3	100	0.0
R. dominica	Adult	83.4±3.2	100	100	100	0.0
	Egg	46.3±2.3	78.3±2.3	95.3±2.3	100	0.0
	Larva	53.2±2.3	80.4±2.3	97.4±4.1	100	0.0
	Pupa	46.1±2.3	75.3±2.3	95.1±5.1	100	0.0
T. castaneum	Adult	86.4±1.3	100	100	100	0.0
	Egg	77.4±4.1	95.1±5.1	100	100	0.0
	Larva	92.1±1.9	100	100	100	0.0
	Pupa	80.6±6.1	100	100	100	0.0
T. granarium larvae	Active	62.1±1.2	93.1±2.3	100	100	0.0
	Diapause	53.4±4.1	80.6±6.0	95.1±5.1	100	0.0

mortality was 46.1 ± 2.3% at 1 day-exposure and complete kill at 5 day-exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominica,*** the necessary exposure time was at least 5 days and the adult of ***R. dominica*** was the most susceptible stage.

T. castaneum:

The obtained percentage mortalities at 1 day-exposure were 86.4 ± 1.3, 77.4 ± 4.1, 92.1 ± 1.9 and 80.6 ± 6.1% for the adult, egg, larva and pupa of ***T. castaneum,*** respectively. Complete mortalities were obtained at 2 day-exposure for the adult, larval and pupal stages and 3 day-exposure for the egg stage. The exposure time for achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions was around 3 days and the eggs of this insect were the most resistant.

T. granarium:

Percentage mortalities obtained for the active and diapausing larvae of ***T. granarium*** at 1 day-exposure were 62.1 ± 1.2 and 53.4 ± 4.1%, respectively. These values increased to 100% at 3 and 5 day-exposure for the active and diapause larvae, respectively. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 5 days and the diapausing larvae were more resistant to phosphine than active one.

In summary, the results showed clearly, that an exposure period of at least 5 days is necessary to achieve total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using 100 ppm of phosphine inside the closed steel bins at grain temperature of 28 ±

2°C.

6b- Efficacy of 100 ppm of phosphine against the tested insect species at 28 ± 2°C, 55 ± 5% R.H. inside the closed fiberglass bins at varying exposure periods:

The obtained results are listed in Table 8b. Clearly, the results given in this table show that the percentage mortalities raised gradually with the increase of the exposure period of the insects to PH_3 inside the bins.

S. oryzae:

Adult percentage mortality of ***S. oryzae*** was 75.3 ± 2.3% at 1 day-exposure and reached complete kill after 2 day-exposure period. At 1 day-exposure, the percentage mortalities of egg, larva and pupa were 36.3 ± 2.3, 38.4 ± 2.3 and 35.8 ± 2.0%, respectively. These values increased to 100% at 7 day-exposure for the immature stages. Accordingly, the exposure time for achieving complete kill for the various stages of ***S. oryzae*** using 100 ppm of phosphine at 28 ± 2°C inside the closed fiber glass bins was at least 7 days and the adults were the most susceptible stage to phosphine.

R. dominica:

Percentage mortality of the adult of ***R. dominica*** at 1day-exposure was 65.4 ± 2.3% and this value increased to complete kill at 2 day-exposure. Egg percentage mortality at 1 day-exposure was 35.5 ± 1.9% and this value reached 100% kill at 7 day-exposure. Larval percentage mortality was 40.4 ± 6.1% at 1 day-exposure and this figure reached complete kill at 5 days post-treatment. Pupal percentage mortality was 33.1 ± 1.3% at 1 day-exposure and this value increased to reach 100% at 7 day-

Table (8b): Responses of the tested stages of various insect species to 100 ppm of phosphine in the closed fiberglass bins at 28 ± 2°C; 55 ± 5% R. H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)					Control
		1	2	3	5	7	
S. oryzae	Adult	75.3±2.3	100	100	100	100	0.0
	Egg	36.3±2.3	50.4±2.4	70.2±1.6	92.1±1.2	100	0.0
	Larva	38.4±2.3	55.6±6.1	75.6±4.0	97.3±3.1	100	0.0
	Pupa	35.8±2.0	50.1±3.2	66.3±3.1	90.2±2.3	100	0.0
R. dominica	Adult	65.4±2.3	100	100	100	100	0.0
	Egg	35.5±1.9	48.6±3.6	66.4±2.0	93.1±2.6	100	0.0
	Larva	40.4±6.1	53.8±3.2	70.4±3.1	100	100	0.0
	Pupa	33.1±1.3	48.4±4.0	65.6±2.4	88.2±3.1	100	0.0
T. castaneum	Adult	73.4±3.1	100	100	100	100	0.0
	Egg	53.1±2.1	70.6±2.1	90.2±1.3	100	100	0.0
	Larva	70.4±1.9	88.4±3.1	100	100	100	0.0
	Pupa	70.6±2.3	80.6±4.1	93.6±2.0	100	100	0.0
T. granarium larvae	Active	44.3±2.0	60.2±1.9	83.4±4.1	100	100	0.0
	Diapause	36.5±2.3	50.4±2.3	72.5±3.2	90.1±2.1	100	0.0

exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominica,*** the necessary exposure time was at least 7 days and the pupal and egg stages of ***R. dominica*** were more resistant to phosphine than the adult and larval stages.

T. castaneum:

At 1 day-exposure, percentage mortalities of the adult, egg, larva and pupa of ***T. castaneum*** were 73.4 ±3.1, 53.1 ± 2.1, 70.4 ± 1.9 and 70.6 ± 2.3%, respectively. In case of the adult stage, complete kill was recorded after 2 days of exposure, while in case of egg and pupa complete kill was recorded after 5 day-exposure, while in case of larva complete mortalities were recorded at 3 day-exposure. The exposure time for achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions was at least 5 days. Meanwhile, the pupae and eggs of this insect species were more resistant to phosphine than the adult and larval stages.

T. granarium:

Percentage mortalities obtained for the active and diapausing larvae of ***T. granarium*** at 1 day-exposure were 44.3 ± 2.0 and 36.5 ± 2.3%, respectively. This value increased to 100% at 5 and 7 day-exposure for the active and diapausing larvae, respectively. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 7 days, whereas the diapausing larvae were more resistant to phosphine than the active one.

Briefly, the results showed clearly, that an exposure period of at least one week is needed to obtain total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using 100 ppm of

phosphine inside the closed fiberglass bins at grain temperature of 28 ± 2°C.

6c- Efficacy of 100 ppm of phosphine against the tested insect species at 28 ± 2°C, 55 ± 5% R.H. inside the closed metal drums at varying exposure periods:

The obtained results are presented in Table 8c. The results show that mortality values increased with increasing the exposure period.

S. oryzae:

For the adult of ***S. oryzae*** mortality value was 83.2 ± 1.6 and 100% at 1 and 2 day-exposure, respectively. Egg percentage mortality was 47.3 ± 4.1% at 1 day-exposure and this value increased to reach 100% at 3 day-exposure period. Larval percentage mortality was 58.3 ± 2.0% at 1 day-exposure and this value raised to 83.1 ± 2.0% after 2 days from treatment and reach complete kill after 3 day-exposure. Pupal percentage mortality reached 47.1 ± 3.2% at 1 day-exposure period and raised to 77.4 ± 4.0% after 2 day-exposure and this value was 100% kill at 5 day-exposure. The exposure time required for achieving complete kill for the various stages of ***S. oryzae*** using 100 ppm of phosphine at 28 ± 2°C inside the closed metal drums was at least 5 days.

R. dominica:

Percentage mortality of the adult of ***R. dominica*** was 83.1 ± 1.6% at 1 day-exposure and this value reached 100% mortality after 2 days of exposure. Egg percentage mortality at 1 day-exposure was 43.2 ± 3.2% and this value increased to complete kill at 5 day-exposure. Larval percentage mortality at 1 day-exposure was 50.4 ± 1.9% and this value raised to 100% at 5 day-

Table (8c): Responses of the tested stages of various insect species to 100 ppm of phosphine in the closed metal drums at 28 ± 2°C; 55 ± 5% R. H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)				Control
		1	2	3	5	
S. oryzae	Adult	83.2±1.6	100	100	100	0.0
	Egg	47.3±4.1	80.1±1.2	100	100	0.0
	Larva	58.3±2.0	83.1±3.4	100	100	0.0
	Pupa	47.1±3.2	77.4±4.0	95.2±4.0	100	0.0
R. dominica	Adult	83.1±3.2	100	100	100	0.0
	Egg	43.2±3.2	76.2±2.4	93.2±1.2	100	0.0
	Larva	50.4±1.9	78.2±3.2	95.2±1.6	100	0.0
	Pupa	44.3±1.9	73.2±1.9	93.1±1.6	100	0.0
T. castaneum	Adult	85.2±1.9	100	100	100	0.0
	Egg	75.3±2.3	93.2±3.2	100	100	0.0
	Larva	92.2±2.1	100	100	100	0.0
	Pupa	83.1±2.4	100	100	100	0.0
T. granarium larvae	Active	60.2±2.4	90.3±3.2	100	100	0.0
	Diapause	53.4±3.2	78.1±3.1	93.1±7.2	100	0.0

exposure. Pupal percentage mortality was 44.3 ± 1.9% at 1 day-exposure and this value increased to reach 100% at 5 day-exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominica,*** the exposure time was at least 5 days and the adult was the most susceptible stage.

T. castaneum:

Adult percentage mortality of ***T. castaneum*** was 85.2 ± 1.9% at 1 day-exposure and this value increased to 100% at 2 day-exposure. Egg percentage mortality was 75.3 ± 2.3% at 1 day-exposure and reached complete kill after 3 day-exposure. Larval percentage mortality was 92.2 ± 2.1% at 1 day-exposure and 100% kill was achieved at 2 day post-treatment. Pupal percentage mortality was 83.1 ± 2.4% at 1 day-exposure and this value reached 100% at 2 day-exposure. The exposure time for achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions was at least 3 days. Also, the eggs were the least susceptible stage

T. granarium:

Percentage mortalities obtained for the active and diapausing larvae of ***T. granarium*** at 1 day-exposure were 60.2 ± 2.4 and 53.4 ± 3.2%, respectively. These values increased to 100% at 3 and 5 day-exposure for the active and diapausing larvae, respectively. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 5 days and the diapausing larvae were more resistant than the active one.

In conclusion, the results showed clearly, that an exposure period of at least 5 days is necessary to obtain total extinction of

the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using 100 ppm of phosphine inside the closed metal drums at grain temperature of 28 ± 2°C.

The obtained results on the efficacy of phosphine against the tested insects are in harmony with the findings of **Lindgren and Vincent, 1966; Bell and Glanville, 1970; How, 1973; Barbare *et al.*, 1976; Bell, 1976 and El-Lakwah *et al.*, 1991 a & b and 1992 a, b & c.**

7- Efficacy of CA of 99% N_2 against the tested insect species at 18 ± 2°C, 55 ± 5% R.H. inside the closed steel bins at varying exposure periods:

The obtained results are listed in Table 9. Clearly, the results shown in this Table revealed that percentage mortalities of the various insects and their developmental stages raised gradually with the increase of the exposure period of the insects to N_2 inside the closed steel bins.

S. oryzae:

At 3 day-exposure, percentage mortalities of the adult, egg, larva and pupa of ***S. oryzae*** were 50.2 ± 6.1, 25.2 ± 3.2, 31.2 ± 6.1 and 20.2 ± 4.1%, respectively. These values increased with the increase of the exposure period to reach complete kill at 10, 35, 28 and 35 day-exposure for the above mentioned immature stages, respectively. The exposure time required for achieving complete kill for the various stages of ***S. oryzae*** using CA of 99% N_2 at 18 ± 2°C inside the closed steel bins was found to be at least 5 weeks. Also, egg and pupal stages were more tolerant to N_2 than adult and larval stages of ***S. oryzae***.

Table (9):. Responses of the tested stages of various insect species to CA of 99 % N_2 in the closed steel bins at 18 ± 2°C, 55 ± 5% R.H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)								Control
		3	5	7	10	14	21	28	35	
S. oryzae	Adult	50.2±6.1	70.4±3.2	88.2±3.1	100	100	100	100	100	0.0
	Egg	25.2±3.2	30.2±3.1	40.2±6.1	51.2±6.1	73.2±6.2	83.2±4.2	91.2±3.1	100	0.0
	Larva	31.2±6.1	36.2±2.1	44.2±3.1	60.2±2.1	80.2±3.1	91.2±6.1	100	100	0.0
	Pupa	20.2±4.1	25.2±6.2	36.4±3.1	46.2±2.6	58.2±7.1	73.2±6.2	83.2±6.1	100	0.0
R. dominica	Adult	40.2±3.1	60.2±3.1	71.2±6.1	90.2±3.1	100	100	100	100	0.0
	Egg	20.2±6.1	28.1±2.1	36.2±4.2	46.2±3.2	70.2±3.1	80.4±3.1	90.2±6.2	100	0.0
	Larva	33.2±6.2	36.5±4.2	40.2±3.1	55.2±8.1	77.2±6.1	85.2±2.1	100	100	0.0
	Pupa	20.2±6.2	25.2±6.3	32.4±3.1	43.2±2.1	53.2±4.2	70.2±6.1	80.2±2.1	100	0.0
T. castaneum	Adult	36.2±3.1	50.2±4.1	66.2±3.1	83.4±2.1	100	100	100	100	0.0
	Egg	36.2±2.1	43.2±4.1	60.2±3.1	71.2±6.1	88.2±2.1	100	100	100	0.0
	Larva	40.2±3.1	70.2±6.1	90.2±3.1	100	100	100	100	100	0.0
	Pupa	30.2±6.1	60.2±4.2	77.3±2.1	90.2±6.1	100	100	100	100	0.0
T. granarium larvae	Active	3.3±2.1	16.2±4.1	28.2±6.3	50.2±4.2	70.4±2.1	83.2±6.1	100	100	0.0
	diapause	0.0	11.3±6.2	23.4±6.1	43.2±2.1	62.4±3.1	77.6±4.1	89.2±3.1	100	0.0

R. dominica:

Adult percentage mortality of ***R. dominica*** was 40.2 ± 3.1% at 3 day-exposure and this value increased to 71.2 ± 6.1% at 7 day-exposure and reached complete kill after 14 day post-treatment. Egg percentage mortality was 20.2 ± 6.1% at 3 day-exposure and reached 100% after 35 day-exposure. Larval percentage mortality was 33.2 ± 6.2% at 3 day-exposure and 100% kill was achieved at 28 day-exposure. Pupal percentage mortality was 20.2 ± 6.2% at 3 day-exposure and complete kill at 35 day-exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominica,*** the exposure time needed was at least 5 weeks and the pupal and egg stages were less susceptible than the other stages of ***R. dominica***.

T. castaneum:

Adult percentage mortality of ***T. castaneum*** was 36.2 ± 3.1% at 3 day-exposure and this value increased to 100% at 14 day-exposure. Egg percentage mortality was 36.2 ± 2.1% at 3 day-exposure and reached complete kill after 21 day-exposure. Larval percentage mortality was 40.2 ± 3.1% at 3 day-exposure and 100% kill was achieved at 10 day post-treatment. Pupal percentage mortality was 30.2 ± 6.1% at 3 day-exposure and this value reached 100% at 14 day-exposure. The exposure time for achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions was at least 3 weeks. Also, the larvae were the most susceptible stage.

T. granarium:

The recorded mortalities for the active and diapausing larvae of ***T. granarium*** at 3 day-exposure were 3.3 ± 2.1 and 0.0, respectively. These values increased to complete mortality at 28

and 35 day post-treatment for the active and diapausing larvae, respectively. The results showed also that the exposure time needed to achieve complete mortalities for active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 5 weeks.

In summary, the results showed clearly, that an exposure period of at least 5 weeks is necessary to achieve total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using CA of 99% N_2 inside the closed steel bins at grain temperature of 18 ± 2°C.

8- Efficacy of CA of 99% N_2 against the tested insect species at 28 ± 2°C, 55 ± 5% R.H. inside the closed steel bins at varying exposure periods:

The obtained results are given in Table 10. The results show clearly that percentage mortalities of the various insects and their immature stages increased with rising the exposure period.

S. oryzae:

At 3 day-exposure, percentage mortalities of the adult, egg, larva and pupa of ***S. oryzae*** were 60.2 ± 2.1, 35.2 ± 2.1, 40.3 ± 4.1 and 30.2 ± 6.1%, respectively. These values increased with the increase of the exposure period to reach complete kill at 7, 28, 21 and 28 day-exposure for the mentioned immature stage, respectively. The exposure time required for achieving complete kill for the various stages of ***S. oryzae*** using CA of 99% N_2 at 28 ± 2°C inside the closed steel bins was at least 4 weeks. It was also clear, that the pupal and egg stages of ***S. oryzae*** were less susceptible to N_2 than the larval and adult stages.

Table (10): Responses of the tested stages of various insect species to CA of 99 % N_2 in the closed steel bins at 28 ±2°C, 55 ±5% R.H. and varying exposure periods.

Insect species	Stage	% Mortality at indicated exposure periods (days)							Control
		3	5	7	10	14	21	28	
S. oryzae	Adult	60.2±2.1	83.1±3.1	100	100	100	100	100	0.0
	Egg	35.2±2.1	41.2±3.2	50.2±6.1	63.2±4.1	85.2±4.1	98.2±3.1	100	0.0
	Larva	40.3±4.1	50.2±3.1	63.2±6.1	80.4±4.1	95.2±6.1	100	100	0.0
	Pupa	30.2±6.1	44.2±3.1	60.2±3.1	66.2±3.1	80.4±2.1	93.2±4.1	100	0.0
R. dominica	Adult	50.4±2.1	70.2±6.1	93.2±4.1	100	100	100	100	0.0
	Egg	33.2±6.1	40.2±3.1	46.4±3.1	60.2±5.1	80.2±4.2	95.4±2.1	100	0.0
	Larva	43.2±6.1	52.4±3.2	65.3±2.1	83.2±6.1	93.2±6.1	100	100	0.0
	Pupa	28.1±4.1	40.2±3.2	53.2±6.1	63.2±4.2	75.4±3.2	90.2±6.1	100	0.0
T. castaneum	Adult	46.2±3.4	66.3±4.1	90.2±5.1	100	100	100	100	0.0
	Egg	40.2±7.1	50.2±3.2	70.4±3.1	85.4±3.1	100	100	100	0.0
	Larva	50.2±6.1	83.2±6.1	100	100	100	100	100	0.0
	Pupa	43.2±1.2	70.2±6.1	85.4±3.1	100	100	100	100	0.0
T. granarium larvae	Active	6.3±2.1	26.2±3.1	38.4±2.1	60.2±3.1	80.2±4.1	99.2±3.1	100	0.0
	diapause	3.3±3.2	16.2±4.1	26.8±3.1	50.2±3.1	70.6±2.1	85.4±3.3	100	0.0

R. dominica:

Percentage mortality of the adult of ***R. dominica*** at 3 day-exposure was 50.4 ± 2.1% and this value increased to complete kill at 10 day-exposure. Egg percentage mortality at 3 day-exposure was 33.2 ± 6.1% and this value reached 100% kill at 28 day-exposure. Larval percentage mortality was 43.2 ± 6.1% at 3 day-exposure and this figure reached complete kill at 21 days post-treatment. Pupal percentage mortality was 28.1 ± 4.1% at 3 day-exposure and this value increased gradually to reach 100% at 28 day-exposure. Under this condition to obtain 100% mortalities for the various stages of ***R. dominica,*** the necessary exposure time was at least 4 weeks. Also, the pupal and egg stages of this insect species were less susceptible to N_2 than the larval and adult stages.

T. castaneum:

Adult percentage mortality of ***T. castaneum*** was 46.2 ± 3.4% at 3 day-exposure and this value increased to 100% at 10 day-exposure. Egg percentage mortality was 30.2 ± 7.1% at 3 day-exposure and reached complete kill after 14 day-exposure. Larval percentage mortality was 50.2 ± 6.1% at 3 day-exposure and 100% kill was achieved at 7 day post-treatment. Pupal percentage mortality was 43.2 ± 1.2% at 3 day-exposure and this value reached 100% at 10 day-exposure. The exposure time for achieving 100% kill for the various stages of ***T. castaneum*** using the above conditions was less than 2 weeks. Also, the larval stage of ***T. castaneum*** was the most susceptible.

T. granarium:

Percentage mortalities obtained for the active and diapausing larvae of ***T. granarium*** at 3 day-exposure were 6.3 ±

2.1 and 3.3 ± 3.2%, respectively. These values increased to 100% at 28 day-exposure for the both instars larvae. The results showed also that the exposure time needed to achieve complete mortalities for the active and diapausing larvae of ***T. granarium*** using the above conditions was found to be at least 4 weeks.

Briefly, the results showed clearly, that an exposure period of at least 4 weeks is needed to obtain total extinction of the populations of the adults and immature stages of ***S. oryzae, R. dominica, T. castaneum*** and ***T. granarium*** by using CA of 99% N_2 inside the closed steel bins at grain temperature of 28 ± 2°C.

Experiments on application of CA of 99% N_2 inside the closed metal drums and the fiberglass bins were not conducted, because of the lower gastightness of the two storage facilities.

9- Efficacy and combined action of 100 ppm of phosphine and 30 ± 5% carbon dioxide against the tested insect species at 18 ± 2°C and 55 ± 5% R.H. inside the closed steel bins at varying exposure periods:

The results of the efficacy and combined action of 100 ppm phosphine with 30 ± 5% CO_2 to the various stages of the tested insect species inside the closed steel bins at 18 ± 2°C and varying exposure periods are given in Tables 11a, b, c.

Co-toxicity values of the mixture at two days exposure period indicated additive effects for the different stages of all tested insect species. (11a).

The results of the same mixture of phosphine and carbon dioxide at 3 days exposure periods are summarized in Table 11 b. The results indicate that the Co-toxicity values resulting from the mixture of the two gases showed additive effects with the various

Table (11a): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside closed steel bins at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 2 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	30.4	100	0.0	d
	Egg	60.2	15.3	80.2	6.2	d
	Larva	65.4	18.2	85.3	2.0	d
	Pupa	60.6	14.3	80.1	6.9	d
R. dominica	Adult	100	20.2	100	0.0	d
	Egg	58.4	15.6	79.3	7.2	d
	Larva	63.2	18.6	83.4	2.0	d
	Pupa	60.1	14.3	80.1	7.7	d
T. castaneum	Adult	100	16.1	100	0.0	d
	Egg	80.2	25.4	93.3	-6.7	d
	Larva	100	36.3	100	0.0	d
	Pupa	85.4	30.2	100	0.0	d
T. granarium larvae	Active	80.1	0.0	90.4	12.9	d
	Diapause	70.3	0.0	80.6	14.7	d

d = additive effects

Table (11b): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside closed steel bins at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 3 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	50.3	100	0.0	d
	Egg	80.2	18.2	90.4	-8.1	d
	Larva	85.1	20.3	93.8	6.2	d
	Pupa	83.4	16.4	90.4	-9.4	d
R. dominica	Adult	100	40.3	100	0.0	d
	Egg	83.6	20.2	91.4	-8.6	d
	Larva	85.4	23.4	95.4	-4.6	d
	Pupa	80.6	18.2	89.3	-9.6	d
T. castaneum	Adult	100	36.1	100	0.0	d
	Egg	97.2	35.3	100	0.0	d
	Larva	100	44.2	100	0.0	d
	Pupa	100	36.1	100	0.0	d
T. granarium larvae	Active	98.1	3.3	100	0.0	d
	Diapause	85.4	0.0	100	17.0	d

d = additive effects

stages of the tested insect species.

After 5 days-exposure, the results given in Table 11 c & fig 10 indicate additive effects for the mixture with the different stages of all tested insect species.

10- Efficacy and combined action of 100 ppm of phosphine and 30 ± 5% carbon dioxide against the tested insect species at 18 ± 2°C and 55 ± 5% R.H. inside the closed fiberglass bins at varying exposure periods:

The combined action of 100 ppm phosphine with 30 ± 5% CO_2 was calculated at following periods of treatments (2, 3, 5 and 7 days). The results were shown in Table (12a, b, c, d). Results revealed clearly that combinations of phosphine and carbon dioxide inside the closed fiberglass bins at grain temperature of 18 ± 2°C and 55 ± 5% R.H. showed in most cases additive effect for the various tested insects and their adult stages sometimes a synergistic (potentiation) effect was achieved.

After 5 days-exposure, the results given in fig 10 indicate additive effects for the mixture with the different stages of all tested insect species.

11- Efficacy and combined action of 100 ppm of phosphine and 30 ± 5% carbon dioxide against the tested insect species at 18 ± 2°C and 55 ± 5% R.H. inside the closed metal drums at varying exposure periods:

The results of the efficacy and combined action of 100 ppm phosphine with 30 ± 5% CO_2 to the various stages of the tested insect species inside the closed metal drums at 18 ± 2°C and varying exposure periods are shown in Tables 13a, b, c.

Co-toxicity values of the mixture at two days exposure

Table (11c): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside closed steel bins at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 5 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	60.2	100	0.0	d
	Egg	95.4	25.3	100	0.0	d
	Larva	100	30.6	100	0.0	d
	Pupa	93.6	24.1	100	0.0	d
R. dominica	Adult	100	50.4	100	0.0	d
	Egg	93.2	23.6	100	0.0	d
	Larva	100	31.4	100	0.0	d
	Pupa	90.3	24.1	100	0.0	d
T. castaneum	Adult	100	44.3	100	0.0	d
	Egg	100	44.6	100	0.0	d
	Larva	100	70.6	100	0.0	d
	Pupa	100	66.2	100	0.0	d
T. granarium larvae	Active	100	26.3	100	0.0	d
	Diapause	100	13.1	100	0.0	d

d = additive effects

Table (12a): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside closed fiberglass bins at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 2 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	20.3	100	0.0	d
	Egg	40.3	10.3	63.1	24.7	s
	Larva	43.4	12.6	66.8	19.3	d
	Pupa	39.6	9.6	62.4	26.8	s
R. dominica	Adult	83.4	16.3	100	0.3	d
	Egg	39.6	12.4	60.1	15.6	d
	Larva	44.6	13.6	63.4	8.9	d
	Pupa	38.6	12.1	60.3	18.9	d
T. castaneum	Adult	95.4	9.6	100	0.0	d
	Egg	60.4	16.2	73.4	-4.2	d
	Larva	77.6	26.8	88.6	-11.4	d
	Pupa	70.6	21.4	90.4	-1.7	d
T. granarium larvae	Active	46.4	0.0	70.3	51.5	s
	Diapause	38.5	0.0	66.6	73.0	s

d = additive effects

s = synergistic effects

Table (12b): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside closed fiberglass bins at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 3 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	25.2	100	0.0	d
	Egg	61.4	13.6	76.2	1.6	d
	Larva	64.6	15.4	80.1	0.1	d
	Pupa	56.4	12.3	75.2	9.5	d
R. dominica	Adult	100	20.2	100	0.0	d
	Egg	58.6	15.6	66.2	-10.8	d
	Larva	60.4	16.3	73.6	-4.0	d
	Pupa	53.2	14.3	70.1	-8.4	d
T. castaneum	Adult	100	20.7	100	0.0	d
	Egg	81.2	20.2	100	0.0	d
	Larva	100	30.1	100	0.0	d
	Pupa	81.4	23.6	100	0.0	d
T. granarium larvae	Active	73.6	0.0	88.4	20.1	s
	Diapause	64.2	0.0	85.6	33.3	s

d = additive effects

s = synergistic effects

Table (12c): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside closed fiberglass bins at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 5 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	50.2	100	0.0	d
	Egg	77.2	21.3	93.6	-5.0	d
	Larva	83.6	25.4	97.4	-2.6	d
	Pupa	75.4	20.6	90.2	-6.0	d
R. dominica	Adult	100	40.3	100	0.0	d
	Egg	80.6	20.2	95.6	-4.4	d
	Larva	86.4	23.6	99.3	-0.7	d
	Pupa	75.1	18.3	90.1	-3.5	d
T. castaneum	Adult	100	36.4	100	0.0	d
	Egg	100	25.6	100	0.0	d
	Larva	100	50.4	100	0.0	d
	Pupa	100	44.6	100	0.0	d
T. granarium larvae	Active	90.4	9.6	100	0.0	d
	Diapause	83.6	3.3	90.4	4.0	d

d = additive effects

Table (12d): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside closed fiberglass bins at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 7 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	70.3	100	0.0	d
	Egg	90.3	25.3	100	0.0	d
	Larva	97.4	28.4	100	0.0	d
	Pupa	90.1	23.1	100	0.0	d
R. dominica	Adult	100	60.6	100	0.0	d
	Egg	93.4	26.2	100	0.0	d
	Larva	100	30.4	100	0.0	d
	Pupa	90.2	26.5	100	0.0	d
T. castaneum	Adult	100	55.4	100	0.0	d
	Egg	100	33.6	100	0.0	d
	Larva	100	70.4	100	0.0	d
	Pupa	100	50.6	100	0.0	d
T. granarium larvae	Active	100	16.3	100	0.0	d
	Diapause	93.4	9.6	100	0.0	d

d = additive effects

period indicated additive effects for the different stages of all tested insect species. (13a).

The results of the same mixture of phosphine and carbon dioxide at 3 days exposure periods are summarized in Table 13b. The results indicate that the Co-toxicity values resulting from the mixture of the two gases showed additive effects with the various stages of the tested insect species with exception the diapausing larvae of ***T. granarium*** whereas, a potentiation effect was shown.

After 5 days-exposure, the results given in Table 13c & fig 10 indicate additive effects for the mixture with the different stages of all tested insect species.

12- Efficacy and combined action of 100 ppm of phosphine and 30 ± 5% carbon dioxide against the tested insect species at 28 ± 2°C and 55 ± 5% R.H. inside the closed steel bins at varying exposure periods:

The results of the efficacy and combined action of 100 ppm phosphine with 30 ± 5% CO_2 to the various stages of the tested insect species inside the closed steel bins at 28 ± 2°C and varying exposure periods are shown in Tables 14a, b.

Co-toxicity values of the mixture at two days exposure period indicated additive effects for the different stages of all tested insect species (Table 14a) with exception of the diapausing larvae of ***T. granarium*** whereas, a synergistic effect was achieved.

The results of the same mixture of phosphine and carbon dioxide at 3 days exposure periods are summarized in Table 14b & Fig 11. The results indicate that the Co-toxicity values resulting from the mixture of the two gases showed additive effects with all

Table (13a): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside closed metal drums at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 2 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	25.3	100	0.0	d
	Egg	58.2	13.6	78.3	9.1	d
	Larva	63.4	16.1	83.6	5.2	d
	Pupa	56.2	12.2	77.4	13.2	d
R. dominica	Adult	100	20.1	100	0.0	d
	Egg	55.1	14.2	77.2	11.4	d
	Larva	60.3	17.3	80.4	3.6	d
	Pupa	53.2	11.1	78.3	21.8	d
T. castaneum	Adult	100	20.1	100	0.0	d
	Egg	78.3	18.3	90.1	-6.7	d
	Larva	100	30.4	100	0.0	d
	Pupa	83.4	25.4	100	0.0	d
T. granarium larvae	Active	77.4	0.0	88.1	13.8	d
	Diapause	70.3	0.0	80.3	14.2	d

d = additive effects

Table (13b): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside closed metal drums at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 3 day exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	46.2	100	0.0	d
	Egg	80.1	17.2	90.2	-7.3	d
	Larva	83.3	20.1	92.4	-7.6	d
	Pupa	80.2	15.1	90.1	-5.5	d
R. dominica	Adult	100	36.2	100	0.0	d
	Egg	80.2	18.3	90.3	-8.3	d
	Larva	82.1	21.4	93.4	-6.6	d
	Pupa	78.3	15.1	86.1	-7.8	d
T. castaneum	Adult	100	33.4	100	0.0	d
	Egg	95.1	25.4	100	0.0	d
	Larva	100	40.3	100	0.0	d
	Pupa	100	33.2	100	0.0	d
T. granarium larvae	Active	95.1	0.0	100	5.1	d
	Diapause	82.3	0.0	100	21.5	s

d = additive effects

s = synergistic effects

Table (13c): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside closed metal drums at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 5 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	50.2	100	0.0	d
	Egg	93.2	23.2	100	0.0	d
	Larva	99.1	28.2	100	0.0	d
	Pupa	90.2	20.2	100	0.0	d
R. dominica	Adult	100	44.2	10	0.0	d
	Egg	90.2	21.3	100	0.0	d
	Larva	98.2	30.2	100	0.0	d
	Pupa	88.1	20.1	100	0.0	d
T. castaneum	Adult	100	36.2	100	0.0	d
	Egg	100	40.2	100	0.0	d
	Larva	100	60.2	100	0.0	d
	Pupa	100	56.2	100	0.0	d
T. granarium larvae	Active	100	16.3	100	0.0	d
	Diapause	100	9.6	100	0.0	d

d = additive effects

Table (14a): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside closed steel bins at grain temperature of 28 ± 2°C and 55 ± 5 % R. H. after 2 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	60.3	100	0.0	d
	Egg	80.1	27.1	90.2	-9.8	d
	Larva	85.6	28.3	96.3	-3.7	d
	Pupa	78.4	26.1	89.3	-10.7	d
R. dominica	Adult	100	50.3	100	0.0	d
	Egg	78.3	25.2	97.2	-12.8	d
	Larva	80.4	30.1	90.2	-9.8	d
	Pupa	75.3	25.2	86.4	-13.6	d
T. castaneum	Adult	100	40.1	100	0.0	d
	Egg	95.1	25.2	100	0.0	d
	Larva	100	46.2	100	0.0	d
	Pupa	100	35.4	100	0.0	d
T. granarium larvae	Active	93.1	0.0	100	7.4	d
	Diapause	80.6	0.0	100	24.1	s

d = additive effects

s = synergistic effects

Table (14b): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside closed steel bins at grain temperature of 28 ± 2°C and 55 ± 5 % R. H. after 3 day exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	73.2	100	0.0	d
	Egg	100	30.4	100	0.0	d
	Larva	100	35.6	100	0.0	d
	Pupa	98.1	30.1	100	0.0	d
R. dominica	Adult	100	60.5	100	0.0	d
	Egg	95.3	33.1	100	0.0	d
	Larva	97.4	38.4	100	0.0	d
	Pupa	95.1	30.1	100	0.0	d
T. castaneum	Adult	100	50.2	100	0.0	d
	Egg	100	30.2	100	0.0	d
	Larva	100	55.3	100	0.0	d
	Pupa	100	40.3	100	0.0	d
T. granarium larvae	Active	100	6.6	100	0.0	d
	Diapause	95.1	0.0	100	5.2	d

d = additive effects

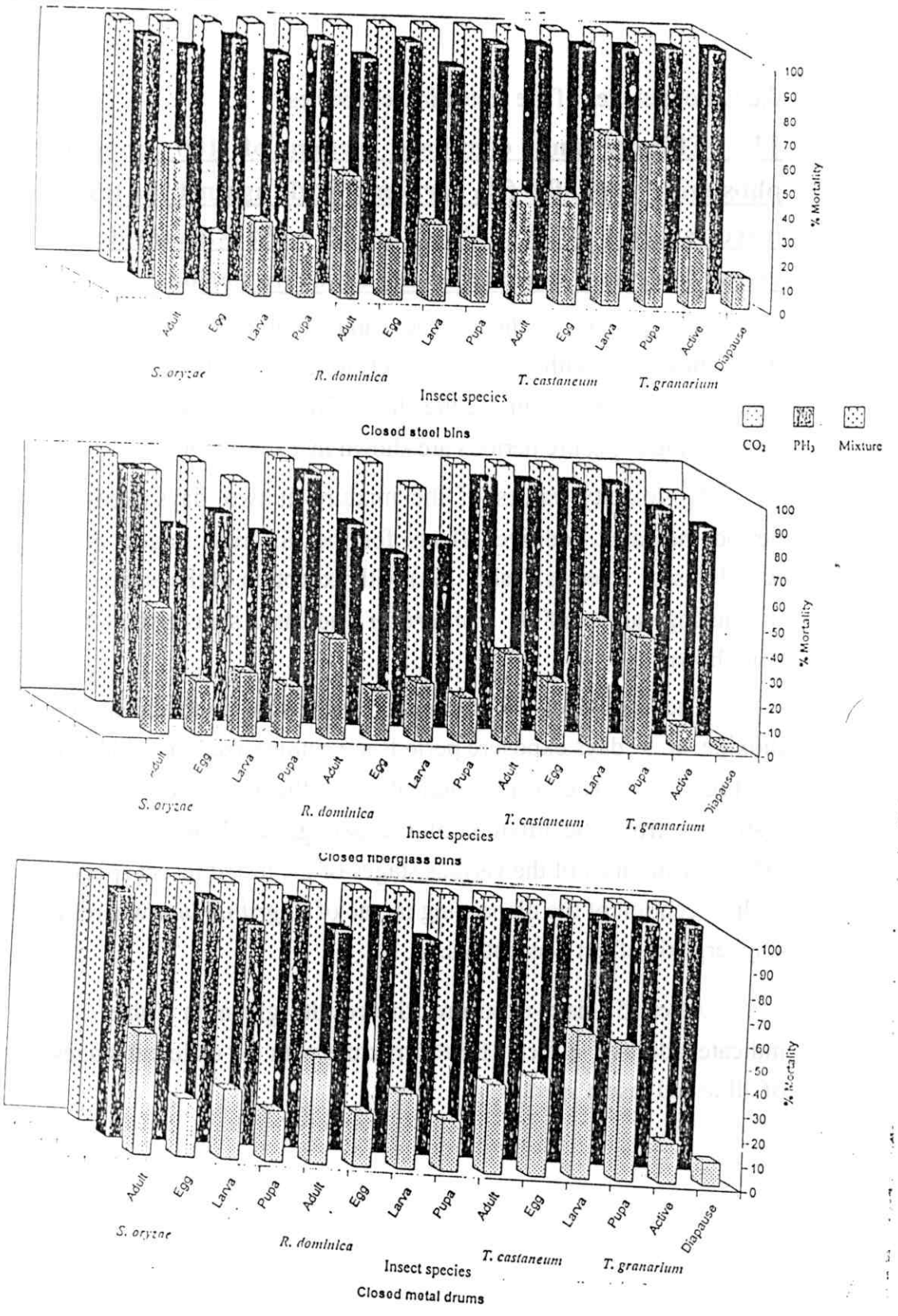

Fig (8): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside storage facilities at grain temperature of 18 ± 2°C and 55 ±

the various stages of the tested insect species.

13- Efficacy and combined action of 100 ppm of phosphine and 30 ± 5% carbon dioxide against the tested insect species at 28 ± 2°C and 55 + 5% R.H. inside the closed fiberglass bins at varying exposure periods:

The results of the efficacy and combined action of 100 ppm phosphine with 30 ± 5% CO_2 to the various stages of the tested insect species inside the closed fiberglass bins at 28 ± 2°C and varying exposure periods are shown in Tables 15a, b, c.

Co-toxicity values of the mixture at two days exposure period indicated additive effects for the different stages of all tested insect species (Table 15a) with exception of the active and diapausing larvae of ***T. granarium*** whereas, a synergistic effect was shown.

The results of the same mixture of phosphine and carbon dioxide at 3 days exposure periods are summarized in Table 15b & Fig 11. The results indicate that the Co-toxicity values resulting from the mixture of the two gases showed additive effects with most of the various stages of the tested insect species with exception of the diapausing larvae of ***T. granarium*** whereas, a synergistic effect was obtained.

After 5 days-exposure, the results given in Table 15c indicate additive effects for the mixture with the different stages of all tested insect species.

Table (15a): Efficacy and combined action of 100 ppm phosphine and 30 ± 5% carbon dioxide to the tested stages of various insect species inside closed fiberglass bins at grain temperature of 28 ± 2°C and 55 ± 5% R. H. after 2 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	30.2	100	0.0	d
	Egg	50.4	16.2	73.4	10.2	d
	Larva	55.6	18.3	76.6	3.7	d
	Pupa	50.1	15.4	73.4	12.1	d
R. dominica	Adult	100	16.3	100	0.0	d
	Egg	48.6	18.3	71.2	6.4	d
	Larva	53.8	20.2	75.4	1.9	d
	Pupa	48.4	16.1	70.1	8.7	d
T. castaneum	Adult	100	9.6	100	0.0	d
	Egg	70.6	20.2	85.4	-6.0	d
	Larva	88.4	30.6	97.1	-2.9	d
	Pupa	80.6	25.3	95.6	-4.4	d
T. granarium larvae	Active	60.2	0.0	83.4	38.5	s
	Diapause	50.4	0.0	78.6	56.0	s

d = additive effects

s = synergistic effects

Table (15b): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside closed fiberglass bins at grain temperature of 28 ± 2°C and 55 ± 5 % R. H. after 3 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	40.2	100	0.0	d
	Egg	70.2	18.6	85.6	-3.6	d
	Larva	75.6	20.3	89.4	-6.8	d
	Pupa	66.3	18.1	83.1	-1.5	d
R. dominica	Adult	100	25.1	100	0.0	d
	Egg	66.4	20.4	83.2	-4.2	d
	Larva	70.4	23.6	87.4	-7.0	d
	Pupa	65.6	20.1	80.2	-6.4	d
T. castaneum	Adult	100	20.1	100	0.0	d
	Egg	90.2	30.2	100	0.0	d
	Larva	100	40.3	100	0.0	d
	Pupa	93.6	30.3	100	0.0	d
T. granarium larvae	Active	83.4	3.3	100	15.3	d
	Diapause	72.5	0.0	90.4	24.7	s

d = additive effects

s = synergistic effects

Table (15c): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside closed fiberglass bins at grain temperature of 28 ± 2°C and 55 ± 5 % R. H. after 5 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	50.1	100	0.0	d
	Egg	92.1	25.2	100	0.0	d
	Larva	97.3	27.4	100	0.0	d
	Pupa	90.2	24.1	100	0.0	d
R. dominica	Adult	100	40.2	100	0.0	d
	Egg	93.1	24.1	100	0.0	d
	Larva	100	28.2	100	0.0	d
	Pupa	88.2	22.6	100	0.0	d
T. castaneum	Adult	100	35.2	100	0.0	d
	Egg	100	38.1	100	0.0	d
	Larva	100	50.1	100	0.0	d
	Pupa	100	36.1	100	0.0	d
T. granarium larvae	Active	100	6.6	100	0.0	d
	Diapause	90.1	3.3	100	0.0	d

d = additive effects

14- Efficacy and combined action of 100 ppm of phosphine and 30 ± 5% carbon dioxide against the tested insect species at 28 ± 2°C and 55 ± 5% R.H. inside the closed metal drums at varying exposure periods:

The results of the efficacy and combined action of 100 ppm phosphine with 30 ± 5% CO_2 to the various stages of the tested insect species inside the closed metal drums at 28 ± 2°C and varying exposure periods are shown in Tables 16a, b.

Co-toxicity values of the mixture at two days exposure period indicated additive effects for the different stages of all tested insect species (Table 16a) with exception of the diapausing larvae of ***T. granarium*** whereas, a synergistic effect was obtained.

The results of the same mixture of phosphine and carbon dioxide at 3 days exposure periods are shown in Table 16b & Fig 11. The results indicate that the Co-toxicity values resulting from the mixture of the two gases showed additive effects with all the various stages of the tested insect species.

15- Efficacy and combined action of 100 ppm of phosphine and 60 ± 5% carbon dioxide against the tested insect species at 18 ± 2°C and 55 ± 5% R.H. inside the closed steel bins at varying exposure periods:

The results of the efficacy and combined action of 100 ppm phosphine with 60 ± 5% CO_2 to the various stages of the tested insect species inside the closed steel bins at 18 ± 2°C and varying exposure periods are shown in Tables 17a, b, c.

Co-toxicity values of the mixture at two days exposure period indicated additive effects for the different stages of all

Table (16a): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside closed metal drums at grain temperature of 28 ± 2°C and 55 ± 5 % R. H. after 2 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	55.2	100	0.0	d
	Egg	80.1	25.1	88.1	-11.9	d
	Larva	83.1	27.4	95.2	-4.8	d
	Pupa	77.4	25.2	86.3	-13.7	d
R. dominica	Adult	100	46.4	100	0.0	d
	Egg	76.2	23.1	85.1	-14.3	d
	Larva	78.2	28.6	88.3	-11.7	d
	Pupa	73.2	21.4	82.6	-12.7	d
T. castaneum	Adult	100	40.1	100	0.0	d
	Egg	93.2	22.1	100	0.0	d
	Larva	100	43.1	100	0.0	d
	Pupa	100	35.1	100	0.0	d
T. granarium larvae	Active	90.3	3.3	100	6.8	d
	Diapause	78.1	0.0	100	28.0	s

d = additive effects

s = synergistic effects

Table (16b): Efficacy and combined action of 100 ppm phosphine and 30 ± 5% carbon dioxide to the tested stages of various insect species inside closed metal drums at grain temperature of 28 ± 2°C and 55 ± 5 % R. H. after 3 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	60.1	100	0.0	d
	Egg	100	28.1	100	0.0	d
	Larva	100	34.1	100	0.0	d
	Pupa	95.2	28.3	100	0.0	d
R. dominica	Adult	100	55.1	100	0.0	d
	Egg	93.2	30.1	100	0.0	d
	Larva	95.2	35.4	100	0.0	d
	Pupa	93.1	26.6	100	0.0	d
T. castaneum	Adult	100	50.1	100	0.0	d
	Egg	100	27.1	100	0.0	d
	Larva	100	55.2	100	0.0	d
	Pupa	100	40.3	100	0.0	d
T. granarium	Active	100	6.6	100	0.0	d
larvae	Diapause	93.1	0.0	100	0.0	d

d = additive effects

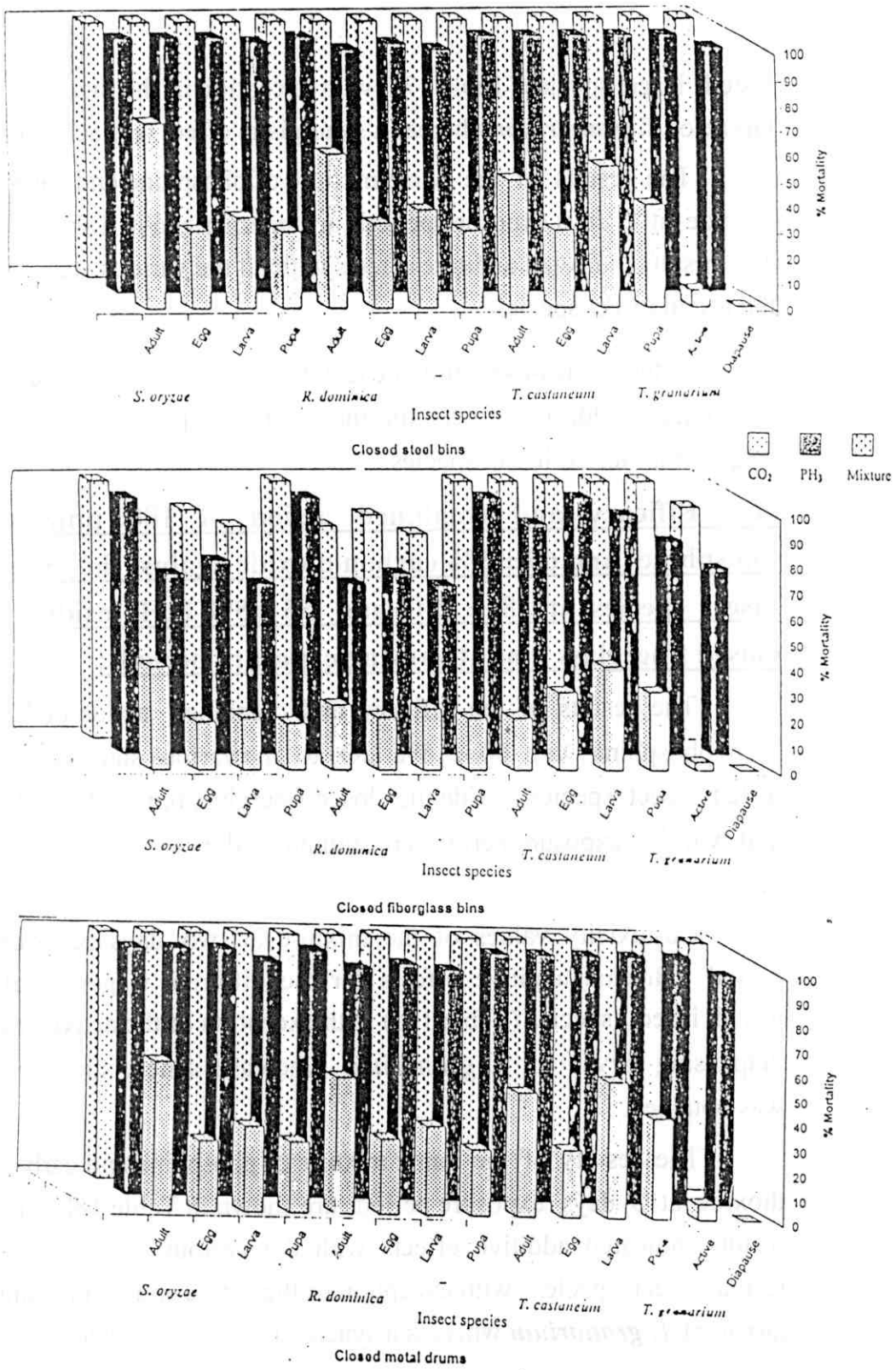

Fig (9): Efficacy and combined action of 100 ppm phosphine and 30 ± 5 % carbon dioxide to the tested stages of various insect species inside storage facilities at grain temperature of 28 ± 2°C and 55 ± 5 % R. H. after 3 days exposure period.

tested insect species (Table 17a) with exception of the diapausing larvae of ***T. granarium*** whereas a synergistic effect was achieved.

The results of the same mixture of phosphine and carbon dioxide at 3 days exposure periods are summarized in Table 17b. The results indicated additive effects with all the various stages of the tested insect species.

After 5 days-exposure, the results given in Table 17c & fig 12 indicate additive effects for the mixture with the different stages of all tested insect species.

16- Efficacy and combined action of 100 ppm of phosphine and 60 ± 5% carbon dioxide against the tested insect species at 18 ± 2°C and 55 ± 5% R.H. inside the closed fiberglass bins at varying exposure periods:

The results of the efficacy and combined action of 100 ppm phosphine with 60 ± 5% CO_2 to the various stages of the tested insect species inside the closed fiberglass bins at 18 ± 2°C and varying exposure periods are summarized in Tables 18a, b, c, d.

Co-toxicity values of the mixture at two days exposure period indicated additive effects for the different stages of all tested insect species (Table 18a) with exception of the active and diapausing larvae of ***T. granarium*** whereas a synergistic effect was obtained.

The results of the same mixture of phosphine and carbon dioxide at 3 days exposure periods are shown in Table 18b. The results indicated additive effects with the various stages of the tested insect species with exception of the active and diapausing larvae of ***T. granarium*** whereas a synergistic effect was shown.

Table (17a): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed steel bins at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 2 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	80.2	100	0.0	d
	Egg	60.1	30.2	90.4	0.1	d
	Larva	68.4	33.1	95.6	-5.8	d
	Pupa	58.4	30.1	89.1	0.7	d
R. dominica	Adult	100	60.2	100	0.0	d
	Egg	60.2	33.1	89.2	-4.4	d
	Larva	65.1	36.2	91.4	-8.6	d
	Pupa	56.4	28.1	86.1	1.9	d
T. castaneum	Adult	100	50.3	100	0.0	d
	Egg	83.1	30.2	99.3	-0.7	d
	Larva	100	70.2	100	0.0	d
	Pupa	83.4	40.2	100	0.0	d
T. granarium larvae	Active	83.2	9.6	97.4	-2.6	d
	Diapause	73.6	3.3	94.6	23.0	s

d = additive effects

s = synergistic effects

Table (17b): Efficacy and combined action of 100 ppm phósphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed steel bins at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 3 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	100	100	0.0	d
	Egg	83.2	40.1	97.2	-2.8	d
	Larva	85.1	43.2	100	0.0	d
	Pupa	82.1	40.2	95.2	-4.8	d
R. dominica	Adult	100	90.2	100	0.0	d
	Egg	80.3	43.2	98.2	-1.8	d
	Larva	83.2	46.2	100	0.0	d
	Pupa	80.6	38.1	94.6	-5.4	d
T. castaneum	Adult	100	86.4	100	0.0	d
	Egg	98.1	44.2	100	0.0	d
	Larva	100	83.2	100	0.0	d
	Pupa	100	80.2	100	0.0	d
T. granarium larvae	Active	100	16.3	100	0.0	d
	Diapause	89.6	9.6	100	0.0	d

d = additive effects

Table (17c): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed steel bins at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 5 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	100	100	0.0	d
	Egg	97.2	50.3	100	0.0	d
	Larva	100	55.6	100	0.0	d
	Pupa	95.4	50.2	100	0.0	d
R. dominica	Adult	100	100	100	0.0	d
	Egg	96.2	55.4	100	0.0	d
	Larva	100	60.3	100	0.0	d
	Pupa	93.1	48.3	100	0.0	d
T. castaneum	Adult	100	100	100	0.0	d
	Egg	100	80.2	100	0.0	d
	Larva	100	100	100	0.0	d
	Pupa	100	100	100	0.0	d
T. granarium larvae	Active	100	26.2	100	0.0	d
	Diapause	100	16.1	100	0.0	d

d = additive effects

Table (18a): Efficácy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed fiberglass bins at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 2 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	35.6	100	0.0	d
	Egg	42.1	20.6	73.4	17.0	d
	Larva	45.2	23.6	77.2	12.2	d
	Pupa	40.6	20.1	71.2	17.2	d
R. dominica	Adult	85.4	30.1	100	0.0	d
	Egg	42.1	18.4	70.6	16.6	d
	Larva	46.2	21.1	75.4	12.0	d
	Pupa	38.6	16.2	70.6	28.8	s
T. castaneum	Adult	97.4	25.3	100	0.0	d
	Egg	62.1	20.1	85.2	3.6	d
	Larva	78.3	38.4	96.4	-17.3	d
	Pupa	72.4	30.1	80.1	-19.9	d
T. granarium larvae	Active	48.2	0.0	80.1	66.2	s
	Diapause	40.4	0.0	77.4	91.5	s

d = additive effects

s = synergistic effects

Table (18b): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed fiberglass bins at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 3 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	68.2	100	0.0	d
	Egg	63.2	27.2	85.4	-5.5	d
	Larva	66.1	24.6	90.1	-0.7	d
	Pupa	60.2	27.1	83.1	-4.8	d
R. dominica	Adult	100	50.2	100	0.0	d
	Egg	60.1	22.6	77.4	-6.4	d
	Larva	63.2	25.3	80.6	-8.9	d
	Pupa	58.4	20.2	78.4	-0.2	d
T. castaneum	Adult	100	48.2	100	0.0	d
	Egg	83.1	20.1	100	0.0	d
	Larva	100	50.2	100	0.0	d
	Pupa	80.4	40.1	100	0.0	d
T. granarium larvae	Active	75.6	3.3	97.2	23.1	s
	Diapause	66.6	0.0	93.1	39.7	s

d = additive effects

s = synergistic effects

After 5 and 7 days-exposure, the results given in Tables 18c&d and fig 12 indicated additive effects for the mixture with the different stages of all tested insect species.

17- Efficacy and combined action of 100 ppm of phosphine and 60 ± 5% carbon dioxide against the tested insect species at 18 ± 2°C and 55 ± 5% R.H. inside the closed metal drums at varying exposure periods:

The results of the efficacy and combined action of 100 ppm phosphine with 60 ± 5% CO_2 to the various stages of the tested insect species inside the closed metal drums at 18 ± 2°C and varying exposure periods are presented in Tables 19a, b, c.

Co-toxicity values of the mixture at two days exposure period indicated additive effects for the different stages of all tested insect species (Table 19a) with exception of the diapausing larvae of ***T. granarium,*** whereas a synergistic effect was obtained.

The results of the same mixture of phosphine and carbon dioxide at 3 days exposure periods are summarized in Table 19b. The results revealed additive effects for all the various stages of the tested insect species.

After 5 days-exposure, the results given in Table 19c & fig 12 indicated also additive effects with the different stages of all tested insect species.

Table (18c): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed fiberglass bins at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 5 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	90.1	100	0.0	d
	Egg	78.2	30.1	9906	-0.4	d
	Larva	85.3	33.2	100	0.0	d
	Pupa	77.3	28.1	96.2	-3.8	d
R. dominica	Adult	100	80.1	100	0.0	d
	Egg	82.6	28.2	98.1	-1.9	d
	Larva	88.4	30.1	100	0.0	d
	Pupa	77.2	27.1	95.2	-4.8	d
T. castaneum	Adult	100	80.6	100	0.0	d
	Egg	100	30.1	100	0.0	d
	Larva	100	66.3	100	0.0	d
	Pupa	100	50.2	100	0.0	d
T. granarium larvae	Active	90.2	13.2	100	0.0	d
	Diapause	85.1	3.3	99.6	12.6	d

d = additive effects

Table (18d): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed fiberglass bins at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 7 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	100	100	0.0	d
	Egg	93.1	35.2	100	0.0	d
	Larva	98.2	40.1	100	0.0	d
	Pupa	92.1	33.2	100	0.0	d
R. dominica	Adult	100	95.2	100	0.0	d
	Egg	95.1	33.2	100	0.0	d
	Larva	100	35.4	100	0.0	d
	Pupa	90.1	30.1	100	0.0	d
T. castaneum	Adult	100	93.2	100	0.0	d
	Egg	100	50.1	100	0.0	d
	Larva	100	93.1	100	0.0	d
	Pupa	100	85.3	100	0.0	d
T. granarium larvae	Active	100	20.2	100	0.0	d
	Diapause	95.4	12.6	100	0.0	d

d = additive effects

Table (19a): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed metal drums at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 2 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	75.6	100	0.0	d
	Egg	57.2	26.4	87.3	4.4	d
	Larva	66.2	28.2	93.2	-1.3	d
	Pupa	55.7	25.4	86.1	6.2	d
R. dominica	Adult	100	56.3	100	0.0	d
	Egg	58.3	28.2	87.1	0.7	d
	Larva	63.2	30.4	89.6	-1.1	d
	Pupa	54.8	23.2	84.1	7.8	d
T. castaneum	Adult	100	46.3	100	0.0	d
	Egg	81.1	26.8	97.3	-2.7	d
	Larva	100	65.6	100	0.0	d
	Pupa	80.2	36.8	100	0.0	d
T. granarium larvae	Active	80.2	6.6	95.6	10.1	d
	Diapause	71.6	0.0	91.3	27.5	s

d = additive effects

s = synergistic effects

Table (19b): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed metal drums at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 3 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	100	100	0.0	d
	Egg	80.2	35.4	95.2	-4.8	d
	Larva	83.6	38.2	98.2	-1.8	d
	Pupa	78.3	33.6	93.6	-6.4	d
R. dominica	Adult	100	85.6	100	0.0	d
	Egg	78.2	38.2	93.2	-6.8	d
	Larva	80.1	40.1	95.6	-4.7	d
	Pupa	76.2	32.6	90.2	-9.8	d
T. castaneum	Adult	100	80.4	100	0.0	d
	Egg	96.2	38.2	100	0.0	d
	Larva	100	80.1	100	0.0	d
	Pupa	100	78.6	100	0.0	d
T. granarium larvae	Active	100	12.3	100	0.0	d
	Diapause	87.6	6.6	100	0.0	d

d = additive effects

Table (19c): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed metal drums at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 5 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	100	100	0.0	d
	Egg	95.3	45.6	100	0.0	d
	Larva	99.2	50.2	100	0.0	d
	Pupa	93.2	44.7	100	0.0	d
R. dominica	Adult	100	100	100	0.0	d
	Egg	93.2	50.2	100	0.0	d
	Larva	97.6	56.4	100	0.0	d
	Pupa	90.1	43.2	100	0.0	d
T. castaneum	Adult	100	100	100	0.0	d
	Egg	100	76.4	100	0.0	d
	Larva	100	100	100	0.0	d
	Pupa	100	99.6	100	0.0	d
T. granarium larvae	Active	100	21.3	100	0.0	d
	Diapause	100	12.6	100	0.0	d

d = additive effects

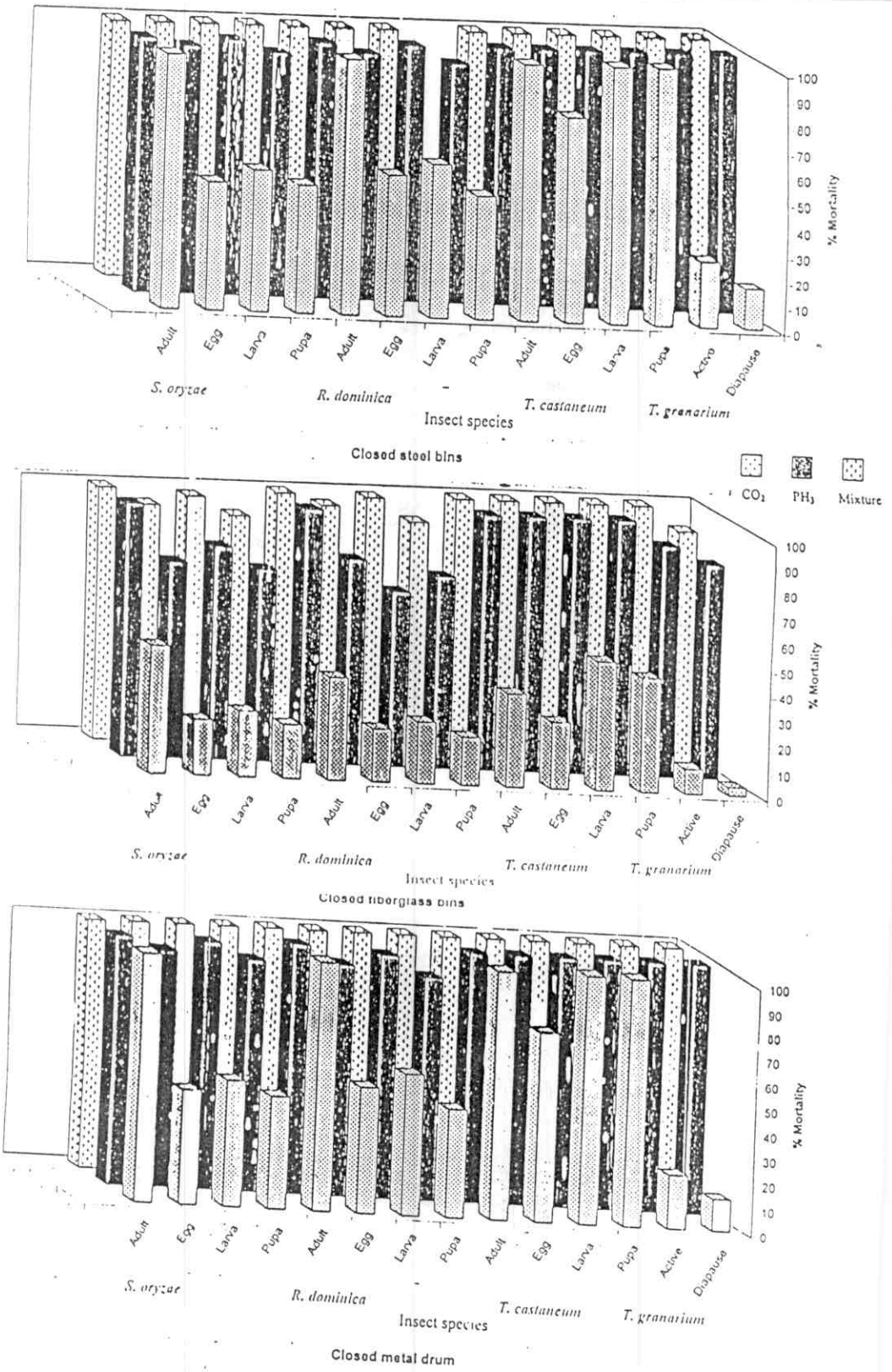

Fig (10): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside storage facilities at grain temperature of 18 ± 2°C

18- Efficacy and combined action of 100 ppm of phosphine and 60 ± 5% carbon dioxide against the tested insect species at 28 ± 2°C and 55 ± 5% R.H. inside the closed steel bins at varying exposure periods:

The results of the efficacy and combined action of 100 ppm phosphine with 60 ± 5% CO_2 to the various stages of the tested insect species inside the closed steel bins at 28 ± 2°C and varying exposure periods are revealed in Tables 20a, b.

Co-toxicity values of the mixture at two days exposure period indicated additive effects for the different stages of all tested insect species (Table 20a).

The results of the same mixture of phosphine and carbon dioxide at 3 days exposure periods are shown in Table 20b & Fig 13. The results indicated additive effects with all the various stages of the tested insect species.

19- Efficacy and combined action of 100 ppm of phosphine and 60 ± 5% carbon dioxide against the tested insect species at 28 ± 2°C and 55 ± 5% R.H. inside the closed fiberglass bins at varying exposure periods:

The results of the efficacy and combined action of 100 ppm phosphine with 60 ± 5% CO_2 to the various stages of the tested insect species inside the closed fiberglass bins at 28 ± 2°C and varying exposure periods are shown in Tables 21a, b, c.

Co-toxicity values of the mixture at two days exposure period indicated additive effects for the different stages of all tested insect species (Table 21a) with exception of the active and diapausing larvae of ***T. granarium,*** whereas a synergistic effect was obtained.

Table (20a): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed steel bins at grain temperature of 28 ± 2°C and 55 ± 5 % R. H. after 2 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	96.2	100	0.0	d
	Egg	83.2	38.1	98.2	-1.8	d
	Larva	87.2	43.3	100	0.0	d
	Pupa	81.1	36.1	95.2	-4.8	d
R. dominica	Adult	100	83.1	100	0.0	d
	Egg	80.2	40.2	97.2	-2.8	d
	Larva	82.3	46.3	100	0.0	d
	Pupa	77.2	35.4	93.2	-6.8	d
T. castaneum	Adult	100	76.3	100	0.0	d
	Egg	97.1	40.3	100	0.0	d
	Larva	100	83.4	100	0.0	d
	Pupa	100	60.3	100	0.0	d
T. granarium larvae	Active	95.6	13.3	100	0.0	d
	Diapause	83.2	6.3	100	11.7	d

d = additive effects

Table (20b): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed steel bins at grain temperature of 28 ± 2°C and 55 ± 5 % R. H. after 3 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	100	100	0.0	d
	Egg	100	50.2	100	0.0	d
	Larva	100	48.1	100	0.0	d
	Pupa	97.2	46.2	100	0.0	d
R. dominica	Adult	100	100	100	0.0	d
	Egg	96.2	53.2	100	0.0	d
	Larva	100	63.1	100	0.0	d
	Pupa	95.2	44.2	100	0.0	d
T. castaneum	Adult	100	100	100	0.0	d
	Egg	100	70.4	100	0.0	d
	Larva	100	100	100	0.0	d
	Pupa	100	90.2	100	0.0	d
T. granarium larvae	Active	100	26.6	100	0.0	d
	Diapause	97.1	13.3	100	0.0	d

d = additive effects

Table (21a): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed fiberglass bins at grain temperature of 28 ± 2°C and 55 ± 5 % R. H. after 2 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	97.3	50.2	100	0.0	d
	Egg	53.2	26.2	85.4	7.5	d
	Larva	55.7	30.4	90.4	4.9	d
	Pupa	50.2	25.1	84.6	11.9	d
R. dominica	Adult	93.2	40.1	100	0.0	d
	Egg	46.3	25.4	83.4	16.3	d
	Larva	50.1	27.1	85.6	10.8	d
	Pupa	46.6	23.2	83.1	19.0	d
T. castaneum	Adult	97.6	38.2	100	0.0	d
	Egg	73.3	30.1	93.6	-6.4	d
	Larva	85.6	46.2	100	0.0	d
	Pupa	83.7	41.1	97.6	-2.4	d
T. granarium larvae	Active	63.1	0.0	93.2	47.7	s
	Diapause	53.4	0.0	85.6	60.2	s

d = additive effects

s = synergistic effects

The results of the same mixture of phosphine and carbon dioxide at 3 days exposure periods are summarized in Table 21 b & Fig 13. The results indicate that the Co-toxicity values resulting from the mixture of the two gases showed additive effects with all the various stages of the tested insect species with exception of the active and diapausing larvae of ***T. granarium***, whereas a synergistic effect was shown.

After 5 days-exposure, the results given in Table 21 reveal additive effects for the mixture with the different stages of all tested insect species.

20- Efficacy and combined action of 100 ppm of phosphine and 60 ± 5% carbon dioxide against the tested insect species at 28± 2°C and 55 ± 5% R.H. inside the closed metal drums at varying exposure periods:

The results of the efficacy and combined action of 100 ppm phosphine with 60 ± 5% CO_2 to the various stages of the tested insect species inside the closed metal drums at 28 ± 2°C and two and three days exposure periods are shown in Tables 22a, b and Fig. 13.

Co-toxicity values of the mixture at two as well as three days exposure period indicated additive effects for the different stages of all tested insect species (Tables 22 a&b).

Table (21b): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed fiberglass bins at grain temperature of 28 ± 2°C and 55 ± 5 % R. H. after 3 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	80.1	100	0.0	d
	Egg	73.2	30.1	95.2	-4.8	d
	Larva	75.6	33.2	100	0.0	d
	Pupa	70.3	28.1	93.2	-5.2	d
R. dominica	Adult	100	75.1	100	0.0	d
	Egg	65.2	28.1	97.2	4.3	d
	Larva	72.4	30.2	99.2	-0.8	d
	Pupa	63.1	26.4	92.2	3.0	d
T. castaneum	Adult	100	73.1	100	0.0	d
	Egg	93.1	40.1	100	0.0	d
	Larva	100	66.2	100	0.0	d
	Pupa	93.2	61.4	100	0.0	d
T. granarium larvae	Active	80.2	15.6	100	4.3	d
	Diapause	73.4	6.9	97.2	21.0	s

d = additive effects

s = synergistic effects

Table (21c): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed fiberglass bins at grain temperature of 28 ± 2°C and 55 ± 5 % R. H. after 5 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	100	100	0.0	d
	Egg	93.2	38.1	100	0.0	d
	Larva	100	43.2	100	0.0	d
	Pupa	91.1	36.1	100	0.0	d
R. dominica	Adult	100	90.1	100	0.0	d
	Egg	95.2	35.1	100	0.0	d
	Larva	100	38.4	100	0.0	d
	Pupa	89.1	33.1	100	0.0	d
T. castaneum	Adult	100	85.1	100	0.0	d
	Egg	100	51.2	100	0.0	d
	Larva	100	90.1	100	0.0	d
	Pupa	100	80.2	100	0.0	d
T. granarium larvae	Active	100	25.6	100	0.0	d
	Diapause	93.2	16.2	100	0.0	d

d = additive effects

Table (22a): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed metal drums at grain temperature of 28 ± 2°C and 55 ± 5 % R. H. after 2 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	93.1	100	0.0	d
	Egg	80.1	34.2	95.3	-4.7	d
	Larva	85.2	40.6	99.4	-0.6	d
	Pupa	78.6	32.8	93.1	-6.9	d
R. dominica	Adult	100	80.6	100	0.0	d
	Egg	78.3	37.3	95.6	-4.4	d
	Larva	80.4	41.3	98.3	-1.7	d
	Pupa	74.3	30.2	90.2	-9.8	d
T. castaneum	Adult	100	70.3	100	0.0	d
	Egg	95.3	36.2	100	0.0	d
	Larva	100	78.6	100	0.0	d
	Pupa	100	55.3	100	0.0	d
T. granarium larvae	Active	93.2	10.2	100	0.0	d
	Diapause	8.3	3.3	100	0.0	d

d = additive effects

Table (22b): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside closed metal drums at grain temperature of 28± 2°C and 55 ± 5 % R. H. after 3 days exposure period.

Insect species	Stage	%Mortality for different treatments			Co-toxicity factor	Type of joint action
		PH_3 alone	CO_2 alone	$PH_3 + CO_2$		
S. oryzae	Adult	100	100	100	0.0	d
	Egg	100	46.3	100	0.0	d
	Larva	100	53.2	100	0.0	d
	Pupa	95.3	42.8	100	0.0	d
R. dominica	Adult	100	100	100	0.0	d
	Egg	93.2	48.2	100	0.0	d
	Larva	100	58.4	100	0.0	d
	Pupa	90.3	38.2	100	0.0	d
T. castaneum	Adult	100	100	100	0.0	d
	Egg	100	64.3	100	0.0	d
	Larva	100	99.2	100	0.0	d
	Pupa	100	86.3	100	0.0	d
T. granarium larvae	Active	100	20.4	100	0.0	d
	Diapause	95.1	9.6	100	0.0	d

d = additive effects

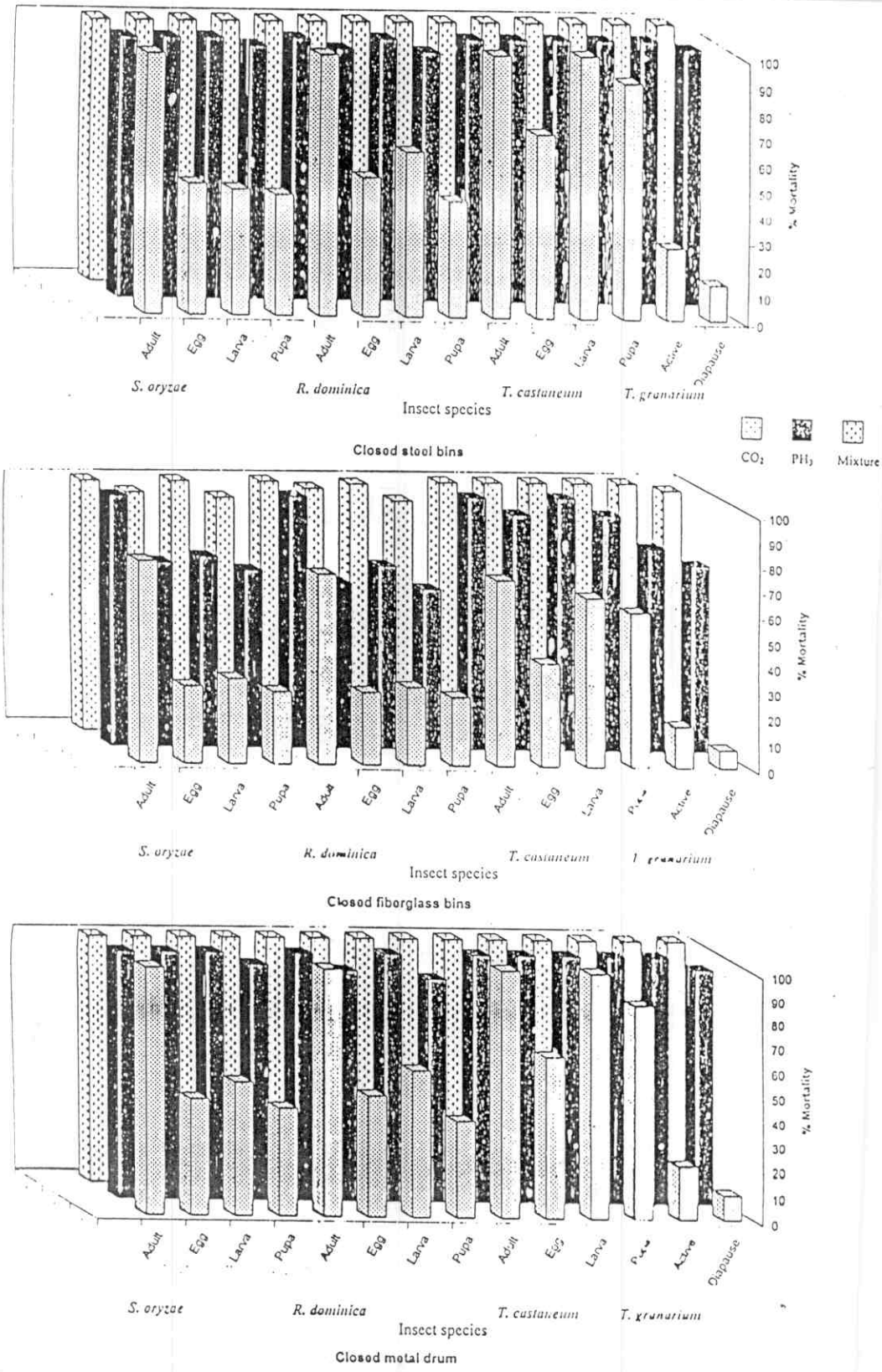

Fig (11): Efficacy and combined action of 100 ppm phosphine and 60 ± 5 % carbon dioxide to the tested stages of various insect species inside storage facilities at grain temperature of 28 ± 2°C and 55 ± 5 % R. H. after 3 days exposure period.

The obtained results on the efficacy of combinations of phosphine plus carbon dioxide against the tested insects are in agreement with those obtained by **Lindgren *et al.*, 1958; Qureshi, *et al.*, 1965; Reynolds *et al.*, 1967; Winks, 1973, 1982 & 1984; Kashi and Bond, 1975; Bell, 1976; Barbara *et al.*, 1976; Desmarchelier, 1984** and **El-Lakwah *et al.*, 1989, 1990, 1991 a, b, 1989, 1990, 1991 a, b and 1992a, b& c.**

Also, this result showed clearly, that addition of carbon dioxide to phosphine gas induced a potentiation action on phosphine against the tested insect species, so that the length of the exposure period could be reduced.

Therefore, combinations of phosphine and carbon dioxide could be used inside the three tested storage facilities to control the various stored product insects and could be considered as an effective control method for replacing methyl bromide.