RESULTS AND DISCUSSION

1- Efficacy of controlled atmospheres (CA) of certain carbon dioxide concentrations against the tested insect species at various grain temperatures:

1-1- Efficacy of CA of 30 ± 5% carbon dioxide (CO_2) against the various insect species at grain temperature of 26 ± 2°C and 55 ± 5 % R. H.

The obtained results are listed in Table 1a and b.

1.1.1. **Responses of the tested stages of various insect species to the CA of 30 ± 5 % CO_2 at 26 ± 2°C and 55 ± 5% R. H.** are given in Table 1a.

Clearly, the results listed in this Table show that the percentage mortalities raised markedly with the increase of the exposure period of the insects to carbon dioxide inside the gastight steel bins.

S. oryzae*:-** Percentage mortality of the adults of ***S. oryzae was 31.1 ± 1.9% at 2 day–exposure and increased to reach 100% after two weeks from treatment. Egg percentage mortality was 31.1 ± 4.1% at 2 day–exposure and this value raised to only 93 ± 3% after3 weeks post – treatment. Larval percentage mortality was 41.8 ± 2.4% at 2 day-exposure and reached 98 ± 1% at 3 week–exposure. Pupal percentage mortality reached 29.6 ± 3.4% at 2 day–exposure and raised only to 80 ± 6% after 3 weeks from treatment.

Table (1a): Responses of the tested stages of various insect species to CA of 30 ± 5 % CO_2 at 26 ± 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	
S. oryzae	Adult	31.1 ± 1.9	62.2 ± 1.9	80.0 ± 1.9	94.4 ± 2.0	96.7 ± 2.0	100	100	0.0
	Egg	31.1 ± 4.1	50.4 ± 2.6	59.4 ± 3.8	65.5 ± 6.0	84.9 ± 2.8	89.8 ± 3.3	93.0 ± 3.0	0.0
	Larva	41.8 ± 2.4	52.6 ± 5.1	63.2 ± 10.2	74.0 ± 2.7	82.2 ± 1.4	88.8 ± 1.4	98.0 ± 1.0	0.0
	Pupa	29.6 ± 3.4	32.5 ± 3.8	35.5 ± 4.4	48.9 ± 9.0	51.3 ± 5.0	63.4 ± 2.8	80.0 ± 6.0	0.0
R. dominica	Adult	10.0 ± 3.3	50.0 ± 3.3	91.1 ± 1.9	93.3 ± 3.4	97.8 ± 1.9	100	100	0.0
	Egg	37.0 ± 9.6	62.0 ± 1.7	64.0 ± 9.0	88.0 ± 5.0	96.0 ± 3.5	99.0 ± 1.7	100	0.0
	Larva	31.6 ± 1.0	36.9 ± 9.1	38.6 ± 1.8	58.7 ± 11.1	61.4 ± 13.4	81.4 ± 8.5	93.0 ± 6.0	0.0
	Pupa	15.8 ± 6.9	18.4 ± 1.7	28.6 ± 8.2	38.2 ± 2.7	52.7 ± 5.5	64.0 ± 4.3	77.0 ± 5.0	0.0
T. castaneum	Adult	5.3 ± 1.0	20.0 ± 3.3	36.7 ± 3.4	72.2 ± 1.9	98.9 ± 1.9	100	100	0.0
	Egg	40.0 ± 5.0	63.0 ± 10.0	85.0 ± 5.0	93.3 ± 2.9	100	100	100	0.0
	Larva	43.0 ± 4.7	61.7 ± 2.3	83.3 ± 5.8	96.7 ± 3.4	97.8 ± 1.9	97.8 ± 1.9	100	0.0
	Pupa	37.8 ± 7.7	49.0 ± 1.9	53.0 ± 3.3	60.4 ± 5.1	69.0 ± 6.9	75.6 ± 5.1	88.0 ± 7.0	0.0
T. granarium larvae	Active	12.2 ± 1.9	18.9 ± 1.9	27.8 ± 1.9	32.2 ± 1.9	54.4 ± 2.0	78.9 ± 1.9	90.0 ± 3.0	0.0
	Diapause	10.0 ± 0.0	11.1 ± 1.9	15.6 ± 2.0	28.9 ± 1.9	50.0 ± 3.3	71.1 ± 5.1	78.0 ± 5.0	0.0

R. dominica:- Percentage mortality of the adults of *R. dominica* at 2 day–exposure was 10 ± 3.3% and this value increased to complete kill at two week–exposure. Egg percentage mortality at 2 day–exposure was 37 ± 9.6% and this value reached 100% kill at 3 week–exposure. Larval percentage mortality was 31.6 ± 1% at 2 day–exposure and this figure reached 93 ± 6% after 3 week–exposure. Pupal percentage mortality was 15.8 ± 6.9% at 2 day–exposure and this value increased to 77 ± 5% only at 3 weeks exposure period.

T. castaneum:- Adult percentage mortality was 5.3 ± 1% at 2 day–exposure and this value increased gradually to reach 100% at 2 week–exposure. Egg percentage mortality was 40 ± 5% at 2 day–exposure and increased to 100% kill at 10 day–exposure. Larval percentage mortality was 43 ± 4.7% at 2 day–exposure and this value increased slowly to reach complete kill at 3 week–exposure. Pupal percentage mortality was 37.8 ± 7.7% at 2 day–exposure and this value increased slowly to reach only 88 ± 7% after 3 weeks exposure period

T. granarium:- Percentage mortality of the active larvae of *T. granarium* was 12.2 ± 1.9% at 2 day–exposure and this value increased to 90 ± 3% at 3 week–exposure. The corresponding values for the diapausing larvae were 10% and 78% at 2 days and 3 week–exposure, respectively.

1.1.2. The lethal times and parameters of probit regression line estimates for the tested stages of various insect species exposed to CA of 30 ± 5% CO_2 at 26 ± 2°C and 55 ± 5% R. H. are presented in Table 1b & Fig (3).

Table (1b): Lethal times and parameters of probit regression line estimates for the tested stages of various insect species, exposed to CA of 30 ± 5% CO_2 at 26 ± 2°C and 55 ± 5 %R. H.

Insect species	Stage	Lethal times and their 95% confidence limits (days)			Slope ± SD	R
		LT_{50}	LT_{90}	LT_{99}		
S. oryzae	Adult	2.6 (2.2 - 3.2)	6.4 (5.1 - 7.9)	13.0 (8.7 - 19.4)	3.3616 ± 0.07	0.9903
	Egg	3.5 (2.9 - 4.2)	15.7 (11.8 - 20.9)	54.0 (31.6 - 92.1)	1.9507 ± 0.09	0.9853
	Larva	3.0 (2.4 - 3.7)	12.7 (9.8 - 16.4)	41.2 (25.0 - 68.0)	2.0413 ± 0.20	0.9705
	Pupa	7.0 (5.6 - 8.8)	69.8 (33.2 – 146.8)	453.8 (124.6 – 1652.0)	1.2852 ± 0.14	0.9493
R. dominica	Adult	3.2 (2.9 - 3.7)	6.1 (5.2 - 7.2)	10.3 (7.8 - 13.4)	4.6528 ± 0.41	0.9710
	Egg	2.7 (2.2 - 3.3)	7.8 (5.9 - 10.3)	18.4 (10.8 - 31.3)	2.7920 ± 0.21	0.9595
	Larva	4.9 (4.2 – 5.8)	24.0 (16.8 – 34.2)	87.4 (46.6 – 164.0)	1.8606 ± 0.34	0.9438
	Pupa	9.1 (7.6 – 10.8)	48.1 (30.0 – 77.2)	187.6 (86.3 – 407.7)	1.7675 ± 0.06	0.9883
T. castaneum	Adult	4.6 (4.1 – 5.1)	8.2 (6.9 – 9.7)	13.0 (10.0 – 17.0)	5.1293 ± 0.78	0.9559
	Egg	2.4 (1.8 – 3.1)	6.0 (4.1 – 8.6)	12.6 (6.3 – 25.4)	3.2149 ± 0.01	0.9999
	Larva	2.3 (1.9 – 2.9)	5.7 (4.5 – 7.0)	11.6 (7.7 – 17.5)	3.3479 ± 0.10	0.9867
	Pupa	3.7 (2.9 – 4.9)	34.4 (19.6 – 60.2)	209.4 (71.2 – 616.1)	1.3313 ± 0.07	0.9749
T. granarium larvae	Active	7.6 (6.7 – 8.7)	26.1 (19.6 – 34.7)	71.2 (44.9 – 113.0)	2.3946 ± 0.33	0.9655
	Diapause	10.0 (8.6 – 11.7)	37.3 (26.3 – 52.6)	109.0 (63.4 – 187.4)	2.2467 ± 0.30	0.9651

R = Correlation coefficient of regression line.

SD = Standard deviation.

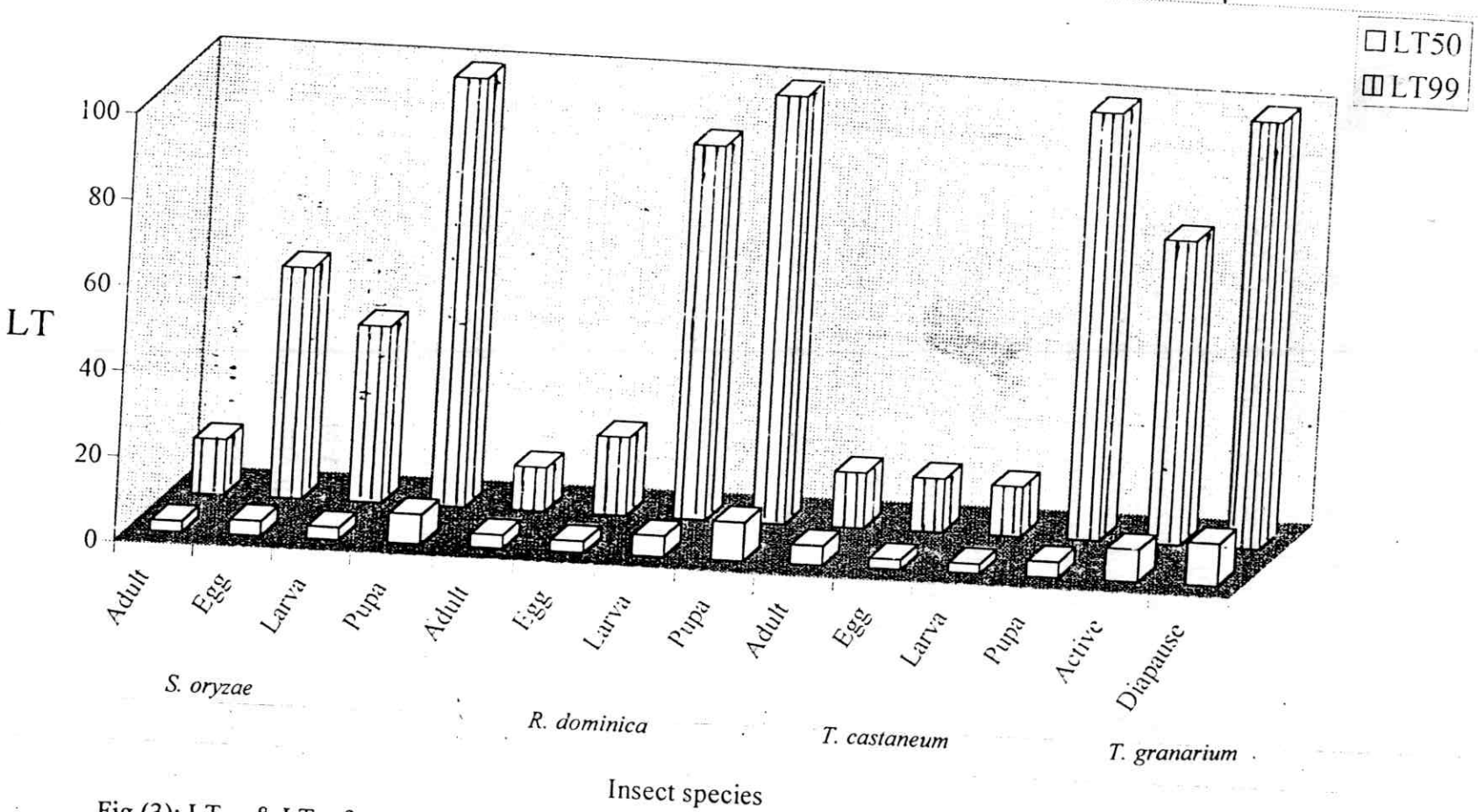

Fig (3): LT_{50} & LT_{99} for the tested stages of various insect species exposed to 30% CO_2 at 26 ± 2°C.

S. oryzae:- The results show that the time required to obtain 50% mortality for the adult, egg, larva and pupa was 2.6, 3.5, 3 and 7 days, respectively. The corresponding values to achieve 99 % kill were 13, 54, 41.2 and 453.8 days, respectively. These figures indicate clearly that the pupa of ***S. oryzae*** was the most tolerant stages to the CA of 30 ± 5% CO_2 at 26 ± 2°C, while the adult was the most sensitive.

R. dominica:- The time needed to achieve 50% kill for the adult, egg, larva and pupa of ***R. dominica*** was 3.2, 2.7, 4.9, and 9.1 days, respectively. To achieve 99% kill these values increased to 10.3, 18.4, 87.4 and 187.6 days for the various stages, respectively. This result reveals that larvae and pupae of *R. dominica* were highly tolerant to the CA of 30 ± 5% CO_2 at 26 ± 2°C than the other stages.

T. castaneum:- The lethal time values to obtain 50% mortality for the adult, egg, larva and pupa of ***T. castaneum*** were 4.6, 2.4, 2.3 and 3.7 days, respectively. The time to achieve 99% kill was 13, 12.6, 11.6 and 209.4 days for the various stages, respectively. This result clearly indicates that the pupal stage of ***T. castaneum*** was the least sensitive to the CA of 30 ± 5% CO_2 at 26 ± 2°C.

T. granarium:- The time needed to obtain 50% mortality for the active larvae of ***T. granarium*** was 7.6 days. This value increased to 71.6 days for achieving 99% kill. The corresponding values were 10 and 109 days for the diapausing larvae, respectively. This result indicates clearly that the active larvae of ***T. granarium*** were more susceptible to the CA of 30 ± 5% CO_2 at 26 ± 2°C than the diapausing larvae.

1.2. Efficacy of CA of 60 ± 5% CO_2 against the various insect species at 26 ± 2°C and 55 ± 5% R. H.:

The results are presented in Table 2a and b.

1.2.1.Responses of the tested stages of various insect species to the CA of 60 ± 5% CO_2 at 26 ± 2°C and 55 ± 5% R. H. are shown in Table 2a. The results show clearly that percentage mortalities were increased with rising the exposure period.

S. oryzae:- Adult percentage mortality of *S. oryzae* was 46 ± 7% at 2 day-exposure and this value raised to 99 ± 1% at 7 day-exposure and reached complete kill after 2 week-exposure period. Egg percentage mortality was 36.4 ± 4% at 2 day-exposure and reached 98.2 ± 3.1% after 3 weeks from treatment. Larval percentage mortality was 44 ± 2% at 2 day-exposure and 100% kill was achieved at 3 week-exposure. Pupal percentage mortality was 32 ± 5% at 2 day-exposure and this value reached 98 ± 2% at 3 weeks post-treatment.

R. dominica:- Adult percentage mortality of *R. dominica* was 56 ± 6% at 2 day-exposure and this value reached 100% mortality at two weeks post-treatment. Egg percentage mortality was 43 ± 2% at 2 day-exposure and reached complete kill after 3 weeks from treatment. Larval percentage mortality was 54% at 2 day-exposure and complete kill was achieved at 3 week-exposure. Pupal mortality was 31 ± 9% at 2 day-exposure and this percentage was 99.9 ± 1.2 at 3 week-exposure.

T. castaneum:- Adult mortality of *T. castaneum* was 49 ± 5% at 2 day-exposure and this value reached rapidly 100% kill at one week-exposure. Egg mortality was 42 ± 7% at 2 day-exposure and this percentage reached complete kill at 2 week-

Table (2a): Responses of the tested stages of various insect species to CA of 60 ± 5% CO_2 at 26 ± 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	
S. oryzae	Adult	46.0 ± 7.0	83.0 ± 5.0	90.3 ± 1.9	99.0 ± 1.0	100	100	0.0
	Egg	36.4 ± 4.0	55.0 ± 3.0	73.3 ± 3.0	84.0 ± 2.0	94.7 ± 7.6	98.2 ± 3.1	0.0
	Larva	44.0 ± 2.0	58.0 ± 6.0	79.5 ± 6.0	98.0 ± 3.0	99.0 ± 1.0	100	0.0
	Pupa	32.0 ± 5.0	43.0 ± 2.0	69.5 ± 9.4	82.2 ± 6.9	90.0 ± 3.0	98.0 ± 2.0	0.0
R. dominica	Adult	56.0 ± 6.0	85.0 ± 3.0	90.0 ± 6.0	98.0 ± 2.0	100	100	0.0
	Egg	43.0 ± 2.0	70.0 ± 5.0	90.0 ± 2.0	93.0 ± 3.0	97.0 ± 3.0	100	0.0
	Larva	54.0 ± 3.0	87.0 ± 3.0	93.0 ± 5.0	95.0 ± 2.0	98.0 ± 2.0	100	0.0
	Pupa	31.0 ± 9.0	50.0 ± 6.0	68.8 ± 7.0	88.0 ± 3.0	93.0 ± 5.2	99.9 ± 1.2	0.0
T. castaneum	Adult	49.0 ± 5.0	87.0 ± 3.0	95.0 ± 2.0	100	100	100	0.0
	Egg	42.0 ± 7.0	80.0 ± 7.0	93.0 ± 3.0	97.0 ± 3.0	100	100	0.0
	Larva	47.0 ± 9.0	87.0 ± 3.0	90.0 ± 5.0	93.0 ± 6.0	100	100	0.0
	Pupa	43.0 ± 2.0	67.0 ± 5.0	78.0 ± 9.0	88.0 ± 3.0	95.0 ± 2.0	100	0.0
T. granarium larvae	Active	15.0 ± 7.0	24.0 ± 5.0	38.9 ± 8.4	67.8 ± 1.9	83.3 ± 3.4	100	0.0
	Diapause	6.0 ± 3.0	18.0 ± 3.0	21.1 ± 5.1	35.5 ± 3.9	79.0 ± 1.9	93.0 ± 5.0	0.0

exposure. Larval mortality was 47 ± 9% at 2 day-exposure and this value reached 100% kill at 2 week-exposure. Pupal mortality was 43 ± 2% at 2 day-exposure and this percentage raised to 95 ± 2% at 2 week and complete kill was recorded after 3 weeks post-treatment.

T. granarium:- Percentage mortalities obtained for the active and diapausing larvae of ***T. granarium*** at 2 day-exposure were 15 ± 7% and 6 ± 3%, respectively. These values increased to 100% and 93 ± 5% at 3 week-exposure for the active and diapausing larvae, respectively.

1.2.2.The lethal times and parameters of probit regression line estimates for the tested stages of various insect species exposed to CA of 60 ± 5% CO_2 at 26 ± 2°C and 55 ± 5% R. H. are given in Table 2b & Fig (4).

S. oryzae:- The results indicate that the time needed to achieve 50% kill for the adult, egg, larva and pupa of ***S. oryzae*** was 2, 2.7, 2.4 and 3.2 days, respectively. To achieve 99% mortality, the figures were 7.6, 26.7, 12.9 and 30.7 days for the adult, egg, larva and pupa, respectively. This result shows clearly that the eggs and the pupae of ***S. oryzae*** were highly tolerant to 60 ± 5% CO_2 at the test temperature than the adult and larval stages.

R. dominica:- The data show that the time obtained to achieve 50% mortality for the adult, egg, larva and pupa of ***R. dominica*** was 1.7, 1.9, 1.2 and 3 days, respectively. To achieve 99% kill the corresponding figures were 9.1, 17.5, 15.5 and 27.1 days for the various stages, respectively. This result indicates

Table (2b): Lethal times and parameters of probit regression line estimates for the tested stages of various insect species, exposed to CA of 60 ± 5 % CO_2 at 26 ± 2°C and 55 ± 5 %R. H.

Insect species	Stage	Lethal times and their 95% confidence limits (days)			Slope ± SD	R
		LT_{50}	LT_{90}	LT_{99}		
S. oryzae	Adult	2.0 (1.5 – 2.7)	4.2 (3.2 – 5.4)	7.6 (4.6 – 12.6)	4.0424 ± 0.18	0.9695
	Egg	2.7 (2.2 – 3.4)	9.6 (7.4 – 12.5)	26.7 (16.4 – 43.4)	2.3525 ± 0.01	0.9992
	Larva	2.4 (2.0 – 3.0)	6.1 (4.8 – 7.8)	12.9 (8.1 – 20.5)	3.2235 ± 0.62	0.9371
	Pupa	3.2 (2.7 – 3.9)	11.2 (8.6 – 14.5)	30.7 (19.2 – 49.3)	2.3787 ± 0.10	0.9887
R. dominica	Adult	1.7 (1.1 – 2.6)	4.3 (3.1 – 5.9)	9.1 (4.5 – 18.3)	3.1584 ± 0.12	0.9667
	Egg	1.9 (1.4 – 2.6)	6.5 (4.8 – 8.7)	17.5 (9.5 – 32.2)	2.4190 ± 0.18	0.9654
	Larva	1.2 (0.7 – 2.1)	5.0 (3.6 – 6.8)	15.5 (7.5 – 32.2)	2.1065 ± 0.28	0.9327
	Pupa	3.0 (2.4 – 3.7)	10.1 (7.2 – 14.1)	27.1 (14.5 – 50.4)	2.4326 ± 0.11	0.9793
T. castaneum	Adult	2.0 (1.6 – 2.5)	3.5 (2.9 – 4.4)	5.6 (3.8 – 8.2)	5.2238 ± 0.29	0.9703
	Egg	2.1 (1.5 – 2.7)	4.5 (3.4 – 6.1)	8.7 (4.9 – 15.2)	3.7130 ± 0.09	0.9818
	Larva	1.6 (1.0 – 2.8)	5.1 (3.4 – 7.7)	13.0 (5.2 – 32.0)	2.5847 ± 0.31	0.8867
	Pupa	2.1 (1.5 – 3.0)	8.7 (6.0 – 12.5)	27.2 (12.7 – 58.3)	2.1001 ± 0.04	0.9887
T. granarium larvae	Active	5.5 (4.6 – 6.6)	18.1 (11.6 – 27.4)	47.7 (24.2 – 94.0)	2.4848 ± 0.08	0.9852
	Diapause	7.5 (6.6 – 8.7)	21.0 (16.0 – 27.5)	48.4 (32.0 – 73.0)	2.8808 ± 0.27	0.9794

R = Correlation coefficient of regression line.

SD = Standard deviation.

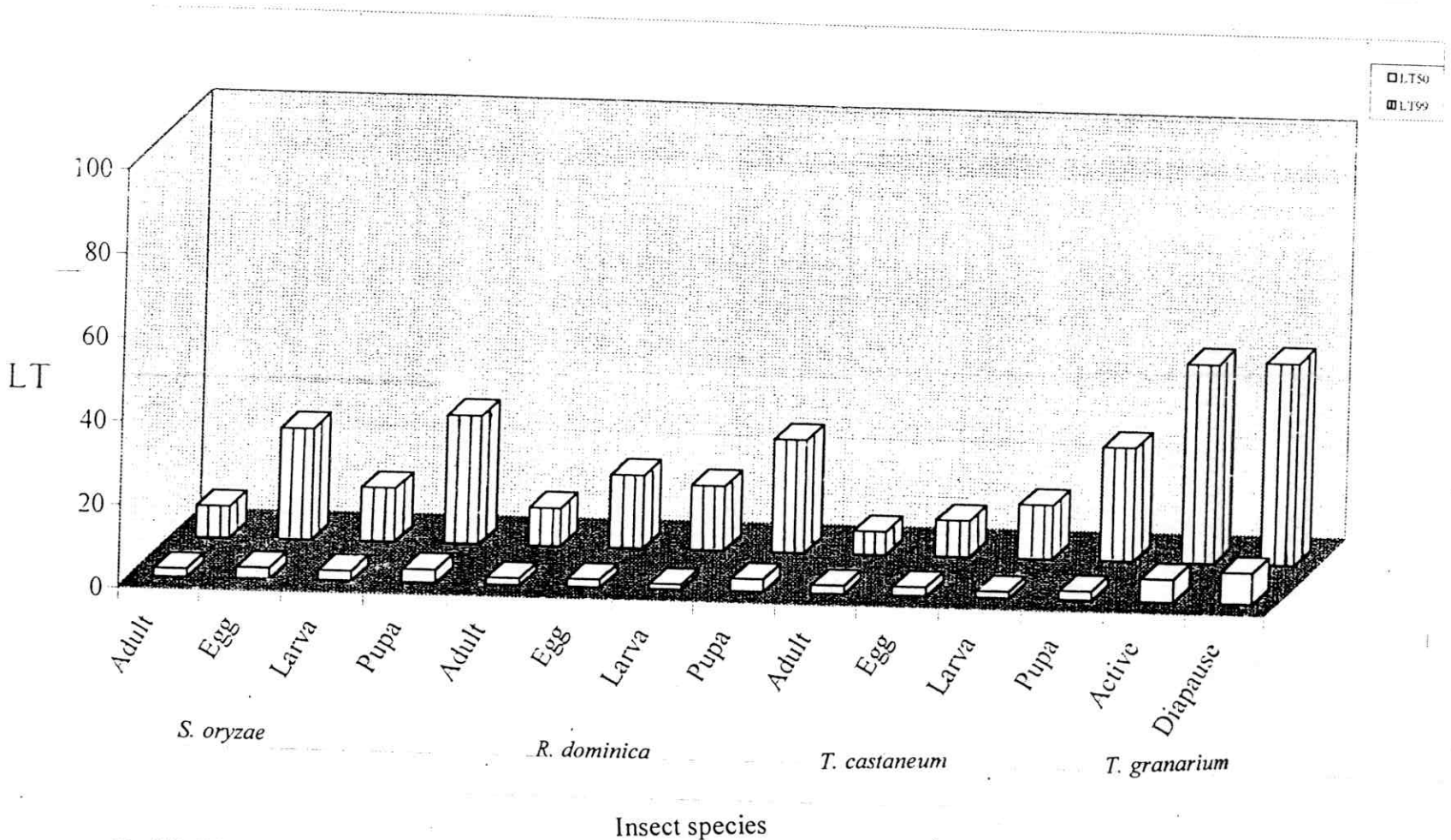

Fig (4): LT_{50} & LT_{99} for the tested stages of various insect species exposed to 60% CO_2 at 26 ± 2°C.

that the pupae and eggs of ***R. dominica*** were more tolerant to the CA of 60 ± 5% CO_2 at the test temperature than the other stages.

T. castaneum:- The time required to obtain 50% mortality for the adult, egg, larva and pupa of ***T. castaneum*** was 2, 2.1, 1.6 and 2.1 days, respectively. For achieving 99% mortality these figures were 5.6, 8.7, 13 and 27.2 days, respectively. This result reveals that the pupa of *T. castaneum* was the most tolerant stage to the CA of 60 ± 5% CO_2 at 26 ± 2°C.

T. granarium:- The results indicate that the time needed to achieve 50% kill for the active and diapausing larvae of ***T. granarium*** was 5.5 and 7.5 days, respectively. To achieve 99% mortality the values were 47.7 and 48.4 days, respectively. This result shows that the diapausing larvae were slightly more tolerant to the CA of 60 ± 5% CO_2 at 26 ± 2°C than active ones.

1.3. Efficacy of CA of 30 ± 5% CO_2 against the various insect species at 15 ± 2°C and 55 ± 5% R. H.

The obtained results are summarized in Table 3a and b.

1.3.1. Responses of the tested stages of various insect species to CA of 30 ± 5% CO_2 at 15 ± 2°C and 55 ± 5% R. H. are shown in Table 3a. The data reveal clearly that percentage mortalities were exposure with the increase of the exposure period.

S. oryzae:- At 3 day-exposure, the percentage mortalities adult, egg, larva and pupa of ***S. oryzae*** were 43 ± 7, 11 ± 3, 36.7 ± 7 and 28 ± 5% for the various stages, respectively. These values increased to 99 ± 1, 95 ± 5, 98 ± 2 and 83 ± 7% at 3

Table (3a): Responses of the tested stages of various insect species to CA of 30 ± 5% CO_2 at 15 ± 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	
S. oryzae	Adult	43.0 ± 7.0	79.0 ± 3.1	93.0 ± 2.3	99.0 ± 1.0	100	0.0
	Egg	11.0 ± 3.0	59.6 ± 6.0	80.0 ± 5.0	95.0 ± 5.0	100	0.0
	Larva	36.7 ± 7.0	81.3 ± 1.5	89.7 ± 2.0	98.0 ± 2.0	100	0.0
	Pupa	28.0 ± 5.0	46.8 ± 2.8	61.0 ± 9.0	83.0 ± 7.0	100	0.0
R. dominic	Adult	49.0 ± 2.0	80.0 ± 3.0	90.0 ± 5.0	99.1 ± 1.0	100	0.0
	Egg	47.0 ± 2.0	63.0 ± 1.3	89.0 ± 3.0	93.0 ± 2.0	100	0.0
	Larva	49.0 ± 6.0	78.0 ± 2.5	83.0 ± 2.0	97.0 ± 3.0	100	0.0
	Pupa	31.0 ± 9.0	56.0 ± 7.5	67.0 ± 9.0	85.0 ± 2.0	100	0.0
T. castaneum	Adult	39.0 ± 7.0	77.8 ± 6.9	93.0 ± 0.0	99.9 ± 1.0	100	0.0
	Egg	28.0 ± 9.0	75.0 ± 5.0	88.3 ± 2.9	97.0 ± 1.5	100	0.0
	Larva	41.0 ± 1.0	78.9 ± 3.8	90.7 ± 1.9	96.9 ± 1.9	100	0.0
	Pupa	38.0 ± 5.0	58.0 ± 5.8	83.0 ± 5.0	90.0 ± 2.0	98.0 ± 3.0	0.0
T. granarium larvae	Active	19.0 ± 5.0	33.0 ± 3.0	47.8 ± 9.0	62.2 ± 7.0	78.0 ± 3.9	0.0
	Diapause	13.0 ± 2.0	18.0 ± 1.9	35.5 ± 6.9	47.0 ± 5.0	69.0 ± 3.3	0.0

week-exposure, respectively. Complete kill for the different insect stages was achieved after 4 weeks exposure period.

R. dominica:- At 3 day-exposure, the recorded percentage mortalities for the adult, egg, larva and pupa of ***R. dominica*** were 49 ± 2, 47 ± 2, 49 ± 6 and 31 ± 9% for the different stages, respectively. These figures increased to reach 99.1 ± 1, 93 ± 2, 97 ± 3 and 85 ± 2% at 3 week-exposure for the various stages, respectively. Complete mortality was obtained after 4 weeks from treatment for all insect stages.

T. castaneum:- The recorded percentage mortalities at 3 day-exposure were 39 ± 7, 28 ± 9, 41 ± 1 and 38 ± 5% for the adult, egg, larva and pupa of ***T. castaneum***, respectively. These percentages reached 99.9 ± 1, 97 ± 1.5, 96.9 ± 1.9 and 90 ± 2% at 3 week-exposure for the various stages, respectively. Complete kill was achieved after 4 weeks exposure period for the adult, egg and larval stages, while only 98 ± 3% mortality was obtained for the pupal stage of this insect species at the above mentioned period of exposure.

T. granarium:- At 3 day-exposure, the obtained mortalities were 19 ± 5% and 13 ± 2% for the active and diapausing larvae of ***T. granarium***, respectively. These values increased to 78 ± 3.9% and 69 ± 3.3% after 4 weeks exposure period for the active and diapausing larvae, respectively.

1.3.2. The lethal times and parameters of probit regression line estimates for the tested stages of various insect species, exposed to CA of 30 ± 5% CO_2 at 15 ± 2°C and 55 ± 5% R. H. are listed in Table 3b & Fig (5).

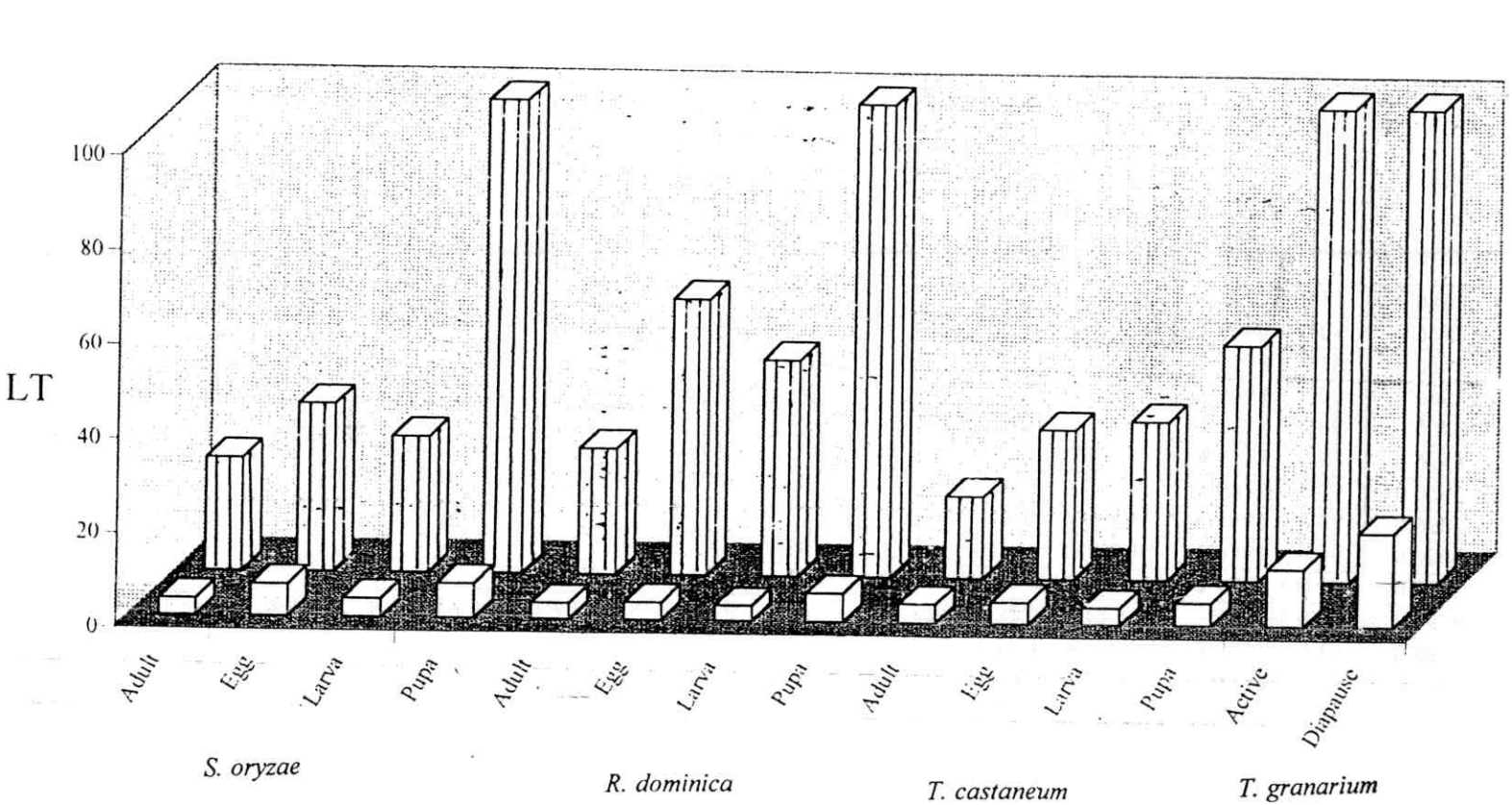

Fig (5): LT_{50} & LT_{99} for the tested stages of various insect species exposed to 20% CO

Table (3b): Lethal times and parameters of probit regression line estimates for the tested stages of various insect species exposed to CA of 30 ± 5% CO2 at 15 ± 2°C and 55 ± 5 %R. H.

Insect species	Stage	Lethal times and their 95% confidence limits (days)			Slope ± SD	R
		LT_{50}	LT_{90}	LT_{99}		
S. oryzae	Adult	3.6 (2.5 – 5.2)	10.2 (7.0 – 14.9)	23.9 (12.0 – 47.4)	2.8296 ± 0.07	0.9903
	Egg	6.8 (5.3 – 8.7)	16.9 (11.9 – 23.9)	35.5 (19.9 – 62.9)	3.2448 ± 0.08	0.9909
	Larva	3.9 (2.7 – 5.6)	11.7 (7.9 – 17.4)	28.8 (14.1 – 59.0)	2.6671 ± 0.10	0.9826
	Pupa	7.3 (4.9 – 10.9)	41.9 (16.2 – 108.3)	174.3 (32.2 – 942.7)	1.6885 ± 0.08	0.9680
R. dominica	Adult	3.3 (2.1 – 5.0)	10.4 (6.9 – 15.5)	26.6 (12.4 – 57.3)	2.5545 ± 0.19	0.9673
	Egg	3.7 (2.2 – 6.1)	16.9 (9.4 – 30.4)	58.4 (18.3 – 186.6)	1.9381 ± 0.06	0.9800
	Larva	3.2 (1.8 – 5.5)	13.8 (8.1 – 23.4)	45.7 (15.6 – 134.2)	2.0083 ± 0.18	0.9505
	Pupa	6.0 (3.9 – 9.3)	34.7 (14.5 – 83.5)	145.0 (28.8 – 729.6)	1.6839 ± 0.05	0.9799
T. castaneum	Adult	4.0 (3.1 – 5.2)	9.0 (6.7 – 12.0)	17.3 (10.7 – 28.1)	3.6524 ± 0.52	0.9558
	Egg	4.6 (3.4 – 6.4)	13.3 (9.0 – 19.6)	31.6 (16.0 – 62.3)	2.7838 ± 0.06	0.9910
	Larva	3.6 (2.3 – 5.5)	12.3 (7.9 – 19.1)	33.6 (14.7 – 76.9)	2.3963 ± 0.02	0.9952
	Pupa	4.8 (3.7 – 6.3)	17.4 (12.8 – 23.7)	49.9 (28.4 – 87.4)	2.2908 ± 0.19	0.9711
T. granarium larvae	Active	12.1 (9.2 – 15.9)	76.7 (37.1 – 158.5)	345.2 (100.1 – 1990.1)	1.6000 ± 0.08	0.9762
	Diapause	19.9 (14.3 – 27.7)	128.2 (51.4 – 319.7)	585.3 (135.0 – 2536.8)	1.5847 ± 0.17	0.9498

R = Correlation coefficient of regression line.

SD = Standard deviation.

S. oryzae:- The results show that the time required to obtain 50% mortality for the adult, egg, larva and pupa of ***S. oryzae*** was 3.6, 6.8, 3.9 and 7.3 days, respectively. To achieve 99% mortality, the values were 23.9, 35.5, 28.8 and 174.3 days for the various stags, respectively. This result clearly reveals that the pupal stage of ***S. oryzae*** was highly tolerant to the CA of 30 ± 5% CO_2 at the low temperature of 15 ± 2°C.

R. dominica:- The data indicate that the time needed to achieve 50% kill for the adult, egg, larva and pupa of ***R. dominica*** was 3.3, 3.7, 3.2 and 6 days, respectively. To achieve 99% mortality, the exposure period was 26.6, 58.4, 45.7 and 145 days for the different stages, respectively. This result indicates that the pupal stage of ***R. dominica*** was the most tolerant stage to this CA of CO_2 at this low temperatures.

T. castaneum:- The results indicate that the time needed to obtain 50% kill for the adult, egg, larva and pupa of ***T. castaneum*** was 4, 4.6, 3.6 and 4.8 days, respectively. To achieve 99% mortality, the recorded values were 17.3, 31.6, 33.6 and 49.9 days for the different stages, respectively. This result reveals that the adult stage of ***T. castaneum*** was the most sensitive to the CA of 30 ± 5% CO_2 at 15 ± 2°C.

T. granarium:- The data indicate that the time required to obtain 50% kill for the active and diapausing larvae of ***T. granarium*** was 12.1 and 19.9 days, respectively. To achieve 99% mortality the values were 345.2 and 385.3 days for the active and diapause larvae, respectively. It was obvious that the larvae of ***T. granarium*** were very highly tolerant to the CA of 30 ± 5% CO_2 at the low temperature of 15 ± 2°C.

1.4. Efficacy of CA of 60 ± 5% CO_2 against the various insect species at 15 ± 2°C and 55 ± 5% R. H.

The obtained results are presented in Table 4a and b.

1.4.1. Responses of the tested stages of various insect species to the CA of 60 ± 5% CO_2 at 15 ± 2°C and 55 ± 5% R. H. are given in Table 4a. The results show that mortality values increased with increasing the exposure period.

S. oryzae:- At 2 day-exposure, percentage mortalities of the adult, egg, larva and pupa of *S. oryzae* were 36.7 ± 3.4, 25.8 ± 1.5, 27 ± 6.3 and 10 ± 6.7%, respectively. In cases of the adult and larval stages, complete mortalities were recorded after 3 weeks exposure period, while at this exposure time, only 99 ± 1% and 87 ± 5% kill was obtained for the egg and pupal stage, respectively.

R. dominica:- Percentage mortalities recorded at 2 day-exposure for the adult, egg, larva and pupa were 38.9 ± 1.9, 12.5 ± 2, 41.2 ± 8.8 and 18.3 ± 4.3%, respectively. Complete mortalities were reached at 2 week-exposure for the adult stage and at 3 weeks exposure period for the larva. While the percentage mortalities of the egg and pupal stages which recorded at 3 week-exposure were 98 ± 2 and 93 ± 3% only.

T. castaneum:- At 2 day-exposure, the recorded percentage mortalities for the adult, egg, larva and pupa of *T. castaneum* were 33.3 ± 2, 36.5 ± 2.9, 34.3 ± 1.9 and 33.3 ± 3%, respectively. Complete kill was achieved at 2 weeks exposure time for all insect stages except the pupal stage which only 93 ± 3% mortality was recorded at this exposure period. However, pupal mortality reached only 98 ± 1% at 3 week-exposure.

Table (4a): Responses of the tested stages of various insect species to CA of 60 ± 5% CO_2 at 15 ± 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	
S. oryzae	Adult	36.7 ± 3.4	65.6 ± 2.0	76.7 ± 3.4	88.9 ± 1.9	99.0 ± 2.0	100	100	0.0
	Egg	25.8 ± 1.5	48.9 ± 5.2	62.0 ± 1.7	79.3 ± 0.5	87.5 ± 0.2	93.0 ± 3.0	99.0 ± 1.0	0.0
	Larva	27.0 ± 6.3	46.0 ± 7.2	69.0 ± 1.5	90.0 ± 3.0	95.0 ± 2.1	99.0 ± 1.1	100	0.0
	Pupa	10.0 ± 6.7	26.2 ± 8.6	35.0 ± 1.9	57.6 ± 1.0	68.2 ± 0.2	79.8 ± 0.2	87.0 ± 5.0	0.0
R. dominic	Adult	38.9 ± 1.9	64.4 ± 2.0	76.7 ± 3.4	88.9 ± 1.9	99.0 ± 2.0	100	100	0.0
	Egg	12.5 ± 2.0	48.7 ± 7.0	62.4 ± 1.6	84.7 ± 2.0	89.8 ± 3.2	91.7 ± 4.8	98.0 ± 2.0	0.0
	Larva	41.2 ± 8.8	60.1 ± 9.4	79.3 ± 3.6	85.5 ± 1.8	93.8 ± 6.2	95.0 ± 3.0	100	0.0
	Pupa	18.3 ± 4.3	39.6 ± 8.0	62.9 ± 2.3	74.7 ± 1.2	80.3 ± 1.2	88.0 ± 3.0	93.0 ± 3.0	0.0
T. castaneum	Adult	33.3 ± 2.0	40.0 ± 3.3	78.9 ± 1.9	86.7 ± 3.4	98.9 ± 1.9	100	100	0.0
	Egg	36.5 ± 2.9	78.5 ± 2.9	83.4 ± 4.7	90.0 ± 3.4	97.0 ± 2.0	100	100	0.0
	Larva	34.3 ± 1.9	68.9 ± 1.9	70.0 ± 5.0	87.0 ± 6.0	95.0 ± 5.0	100	100	0.0
	Pupa	33.3 ± 3.0	55.7 ± 1.9	66.0 ± 7.0	79.0 ± 9.0	86.0 ± 6.0	93.0 ± 3.0	98.0 ± 1.0	0.0
T. granarium larvae	Active	14.4 ± 2.0	20.7 ± 3.4	28.9 ± 5.1	44.4 ± 5.1	62.2 ± 3.9	75.0 ± 2.4	95.0 ± 3.0	0.0
	Diapause	11.1 ± 5.1	15.7 ± 2.0	19.0 ± 5.1	27.8 ± 3.9	42.2 ± 5.1	61.7 ± 2.3	87.0 ± 5.0	0.0

T. granarium:- The recorded mortality values at 2 day-exposure were 14.4 ± 2 and 11.1 ± 5.1% for the active and diapausing larvae of ***T. granarium***, respectively. These values increased to reach 95 ± 3% and 87 ± 5% at 3 weeks exposure time for the active and diapause larvae, respectively.

1.4.2. The lethal times and parameters of probit regression line estimates for the tested stages of various insect species, exposed to CA of 60 ± 5% CO_2 at 15 ± 2°C and 55 ± 5% R. H. are summarized in Table 4b & Fig (6).

S. oryzae:- The results show that the time needed to achieve 50% mortality for the adult, egg, larva and pupa of ***S. oryzae*** was 2.6, 3.5, 3.2 and 6.4 days, respectively. To obtain 99% kill these values were 12.3, 25.2, 14.9 and 63.4 days for the different stages, respectively. This result indicates that the pupa and egg were more tolerant to the CA of 60 ± 5% CO_2 at the low temperature of 15 ± 2°C than the other insect stages.

R. dominica:- The time required to obtain 50% kill for the adult, egg, larva and pupa of ***R. dominica*** was 2.6, 3.8, 2.4 and 4.1 days, respectively. To achieve 99% mortality, the time recorded was 12.4, 24.9, 24.7 and 44.6 days for the various insect stages, respectively. This result shows that the pupa of ***R. dominica*** was the most tolerant stage to this CA at low temperature.

T. castaneum:- The data indicate that the time required to achieve 50% mortality for the adult, egg, larva and pupa was 3, 2.2, 2.6 and 3 days, respectively. To achieve 99% mortality, the values were 12.2, 14.8, 19.2 and 31.5 days for the different stages, respectively. These figures show clearly that the pupa of

Table (4b): Lethal times and parameters of probit regression line estimates for the tested stages of various insect species, exposed to CA of 60 ± 5% CO_2 at 15 ± 2°C and 55 ± 5 %R. H.

Insect species	Stage	Lethal times and their 95% confidence limits (days)			Slope ± SD	R
		LT_{50}	LT_{90}	LT_{99}		
S. oryzae	Adult	2.6 (2.2 – 3.1)	6.1 (4.9 – 7.5)	12.3 (8.3 – 18.2)	3.4273 ± 0.26	0.9659
	Egg	3.5 (3.0 – 4.0)	10.4 (8.6 – 12.5)	25.2 (18.1 – 35.2)	2.7094 ± 0.12	0.9902
	Larva	3.2 (2.8 – 3.6)	7.5 (6.3 – 8.9)	14.9 (11.1 – 20.1)	3.4689 ± 0.07	0.9946
	Pupa	6.4 (5.6 – 7.3)	22.7 (17.4 – 29.5)	63.4 (40.7 – 98.7)	2.3405 ± 0.06	0.9927
R. dominica	Adult	2.6 (2.1 – 3.1)	6.1 (4.9 – 7.6)	12.4 (8.3 – 18.4)	3.3872 ± 0.25	0.9668
	Egg	3.8 (3.4 – 4.4)	10.8 (9.0 – 12.9)	24.9 (18.3 – 33.9)	2.8667 ± 0.33	0.9758
	Larva	2.4 (1.9 – 3.0)	8.6 (6.7 – 11.1)	24.7 (14.9 – 40.9)	2.2794 ± 0.03	0.9938
	Pupa	4.1 (3.5 – 4.8)	15.3 (12.1 – 19.4)	44.6 (29.0 – 68.4)	2.2509 ± 0.10	0.9876
T. castaneum	Adult	3.0 (2.6 – 3.5)	6.5 (5.4 – 7.9)	12.2 (8.7 – 17.1)	3.8494 ± 0.28	0.9708
	Egg	2.2 (1.7 – 2.9)	6.3 (4.9 – 8.1)	14.8 (9.0 – 24.4)	2.8188 ± 0.17	0.9669
	Larva	2.6 (2.1 – 3.3)	7.8 (5.9 – 10.5)	19.2 (11.0 – 33.5)	2.6821 ± 0.15	0.9686
	Pupa	3.0 (2.5 – 3.6)	11.0 (8.8 – 13.7)	31.5 (20.7 – 47.8)	2.2885 ± 0.07	0.9923
T. granarium larvae	Active	6.6 (5.8 – 7.5)	21.3 (16.4 – 27.6)	55.1 (36.1 – 84.2)	2.5268 ± 0.34	0.9677
	Diapause	9.8 (8.3 – 11.4)	38.1 (26.3 – 55.3)	115.9 (64.4 – 208.5)	2.1643 ± 0.43	0.9463

R = Correlation coefficient of regression line.

SD = Standard deviation.

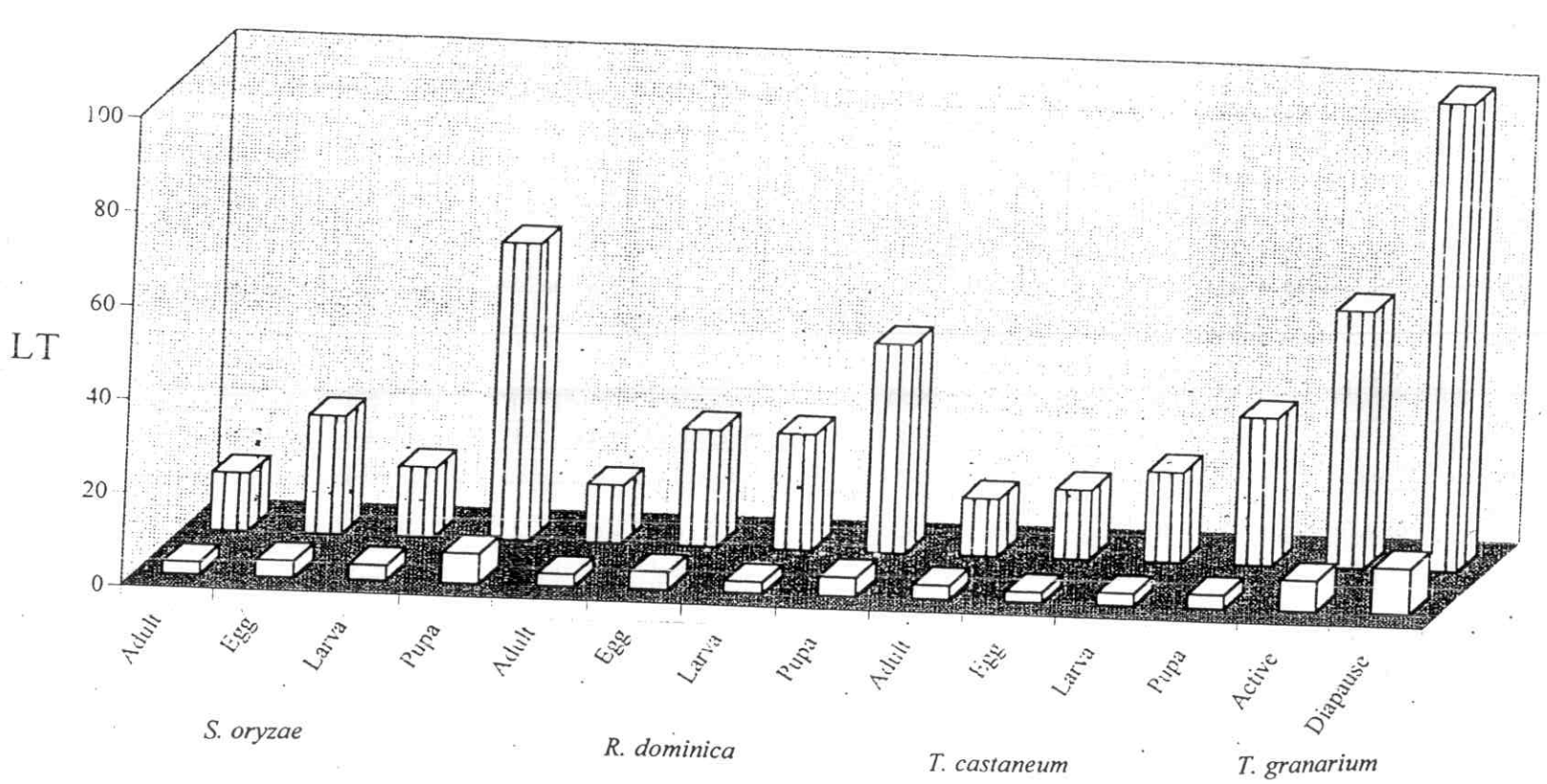

Fig (6): LT_{50} & LT_{99} for the tested stages of various insect species exposed to 60% CO_2 at 15 ± 2°C.

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RESULTS AND DISCUSSION

T. castaneum was the most tolerant stage to the CA of 60 ± 5% CO_2 at the low temperature of 15 ± 2°C.

T. granarium:- The results indicate that the time needed to obtain 50% mortality for the active and diapausing larvae of *T. granarium* was 6.6 and 9.8 days, respectively. To achieve 99% kill, the values were 55.1 and 115.9 days, respectively. This result clearly reveals that the diapausing larvae of ***T. granarium*** were more tolerant to the CA of 60 ± 5% CO_2 at 15 ± 2°C than the active larvae.

1.5. Efficacy of CA of 80 ± 5% CO_2 against the various insect species at 15 ± 2°C and 55 ± 5% R. H.

The results are recorded in Table 5a and b.

1.5.1. Responses of the tested stages of various insect species to the CA of 80 ± 5% CO_2 at 15 ± 2°C and 55 ± 5% R. H. are presented in Table 5a. The obtained data show that percentage mortalities were increased with rising the exposure period.

S. oryzae:- At 2 day-exposure, the resulted mortalities of the adult, egg, larva and pupa of ***S. oryzae*** were 48.4 ± 2.3, 44.4 ± 1.7, 45.4 ± 2.5 and 33 ± 3.3%, respectively. These values increased to reach 100% mortality after 10 day-exposure for the adult and egg stages, while the values for the larva and pupa were 99.6 ± 0.6% and only 78 ± 2.3%, respectively at the mentioned exposure period. Increasing the exposure time to two weeks resulted in complete mortality for the larval stage of ***S. oryzae*** and 89 ± 5% kill for its pupal stage. However, at 3 week-exposure the obtained pupal mortality was 98 ± 1%.

Table (5a): Responses of the tested stages of various insect species to CA of 80 ± 5% CO_2 at 15 ± 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	
S. oryzae	Adult	48.4 ± 2.3	73.3 ± 0.0	85.0 ± 2.4	99.0 ± 0.0	100	100	100	0.0
	Egg	44.4 ± 1.7	64.2 ± 5.2	87.8 ± 0.0	99.6 ± 0.6	100	100	100	0.0
	Larva	45.4 ± 2.5	65.0 ± 2.5	81.5 ± 1.3	98.2 ± 0.0	99.6 ± 0.6	100	100	0.0
	Pupa	33.0 ± 3.3	51.8 ± 2.0	68.8 ± 3.9	72.0 ± 0.6	78.0 ± 2.3	89.0 ± 5.0	98.0 ± 1.0	0.0
R. dominica	Adult	83.4 ± 4.7	91.7 ± 2.3	96.0 ± 2.0	99.0 ± 1.0	100	100	100	0.0
	Egg	42.4 ± 3.3	53.9 ± 0.0	74.7 ± 3.3	79.3 ± 3.3	95.0 ± 3.0	100	100	0.0
	Larva	24.1 ± 6.4	32.2 ± 2.6	47.3 ± 3.8	70.5 ± 1.3	87.5 ± 2.6	96.0 ± 0.0	100	0.0
	Pupa	28.0 ± 2.1	31.0 ± 2.1	42.3 ± 18.0	72.3 ± 1.2	87.8 ± 1.2	93.0 ± 3.0	97.0 ± 3.0	0.0
T. castaneum	Adult	76.7 ± 4.7	85.0 ± 2.4	95.0 ± 1.0	99.0 ± 1.0	100	100	100	0.0
	Egg	67.5 ± 3.5	88.3 ± 5.8	93.3 ± 2.9	99.0 ± 1.0	100	100	100	0.0
	Larva	76.7 ± 4.7	88.4 ± 2.3	96.0 ± 3.0	98.0 ± 2.0	100	100	100	0.0
	Pupa	71.7 ± 2.3	81.7 ± 2.3	93.0 ± 2.4	98.0 ± 1.0	100	100	100	0.0
T. granarium larvae	Active	25.0 ± 2.4	35.0 ± 2.4	43.3 ± 0.0	61.7 ± 2.3	71.7 ± 2.3	91.7 ± 2.3	99.9 ± 2.4	0.0
	Diapause	13.2 ± 3.5	18.0 ± 3.3	22.2 ± 1.9	35.0 ± 2.4	45.0 ± 2.4	73.4 ± 4.7	93.0 ± 2.0	0.0

R. dominica:- The resulted mortalities at 2 day-exposure were 83.4 ± 4.7, 42.4 ± 3.3, 24.1 ± 6.4 and 28 ± 2.1% for the adult, egg, larva and pupa of ***R. dominica***, respectively. At 10-day-exposure, the values increased to reach 100, 95 ± 3, 87.5 ± 2.6 and 87.8 ± 1.2% for the various stages, respectively. At 3 week-exposure complete mortalities were achieved for the egg and larval stages, while the percentage mortality of the pupal stage was only 97 ± 3%.

T. castaneum:- At 2 day-exposure, the recorded mortalities were 76.7 ± 4.7, 67.5 ± 3.5, 76.7 ± 4.7 and 71.7 ± 2.3% for the adult, egg, larva and pupa of ***T. castaneum***, respectively. These values reached 100% kill at 10 days exposure period for all stages of this insect species.

T. granarium:- At 2 day-exposure, percentage mortalities of the active and diapausing larvae of ***T. granarium*** were 25 ± 2.4 and 13.2 ± 3.5%, respectively. These values increased to 99.9 ± 2.4 and 93 ± 2% for the active and diapause larvae at 3 weeks exposure period, respectively.

1.5.2. The lethal times and parameters of probit regression line estimates for the tested stages of various insect species, exposed to CA of 80 ± 5% CO_2 at 15 ± 2°C and 55 ± 5% R. H. are given in Table 5b & Fig (7).

S. oryzae:- The results indicate that the time required to achieve 50% kill for the adult, egg, larva and pupa of ***S. oryzae*** was 2.2, 2.4, 2.4 and 3.7 days, respectively. To obtain 99% mortality the values were 8.3, 7.1, 8.7 and 46.3 days, for the different stages, respectively. It was evident, that the pupal stage

Table (5b): Lethal times and parameters of probit regression line estimates for the tested stages of various insect species, exposed to CA of 80 ± 5% CO_2 at 15 ± 2°C and 55 ± 5 %R. H.

Insect species	Stage	Lethal times and their 95% confidence limits (days)			Slope ± SD	R
		LT_{50}	LT_{90}	LT_{99}		
S. oryzae	Adult	2.2 (1.7 – 2.8)	4.5 (3.4 – 5.9)	8.3 (4.9 – 14.0)	3.9642 ± 0.27	0.9538
	Egg	2.4 (2.0 – 2.8)	4.3 (3.5 – 5.4)	7.1 (4.7 – 10.7)	4.8679 ± 0.37	0.9579
	Larva	2.4 (2.0 – 2.8)	4.8 (4.0 – 5.8)	8.7 (6.2 – 12.1)	4.1068 ± 0.30	0.9726
	Pupa	3.7 (3.2 – 4.4)	15.0 (11.6 – 19.3)	46.3 (28.6 – 75.0)	2.1289 ± 1.23	0.8631
R. dominica	Adult	0.8 (0.2 – 3.1)	2.8 (1.8 – 4.2)	7.7 (2.7 – 21.9)	2.3632 ± 0.03	0.9856
	Egg	2.6 (2.1 – 3.3)	8.7 (6.2 – 12.0)	22.9 (12.1 – 43.4)	2.4734 ± 0.11	0.9721
	Larva	4.2 (3.7 – 4.8)	11.4 (9.1 – 14.2)	25.8 (17.6 – 37.7)	2.9374 ± 0.21	0.9774
	Pupa	4.2 (3.7 – 4.8)	12.6 (10.3 – 15.5)	31.1 (22.0 – 44.0)	2.6723 ± 0.28	0.9764
T. castaneum	Adult	1.2 (0.6 – 2.6)	3.4 (2.4 – 4.7)	7.8 (3.4 – 17.6)	2.8897 ± 0.05	0.9819
	Egg	1.4 (0.8 – 2.5)	3.6 (2.6 – 4.9)	7.7 (3.8 – 15.7)	3.1428 ± 0.10	0.9726
	Larva	1.0 (0.4 – 2.7)	3.3 (2.3 – 4.8)	8.8 (3.2 – 24.1)	2.4499 ± 0.002	0.9990
	Pupa	1.3 (0.7 – 2.6)	3.9 (2.7 – 5.6)	9.6 (3.9 – 23.5)	2.6869 ± 0.03	0.9892
T. granarium larvae	Active	4.4 (4.0 – 4.9)	11.0 (9.4 – 12.8)	22.9 (17.7 – 29.6)	3.2633 ± 1.65	0.9145
	Diapause	7.9 (6.9 – 9.1)	27.0 (20.1 – 36.3)	73.4 (45.8 – 117.7)	2.4063 ± 0.61	0.9399

R = Correlation coefficient of regression line.

SD = Standard deviation.

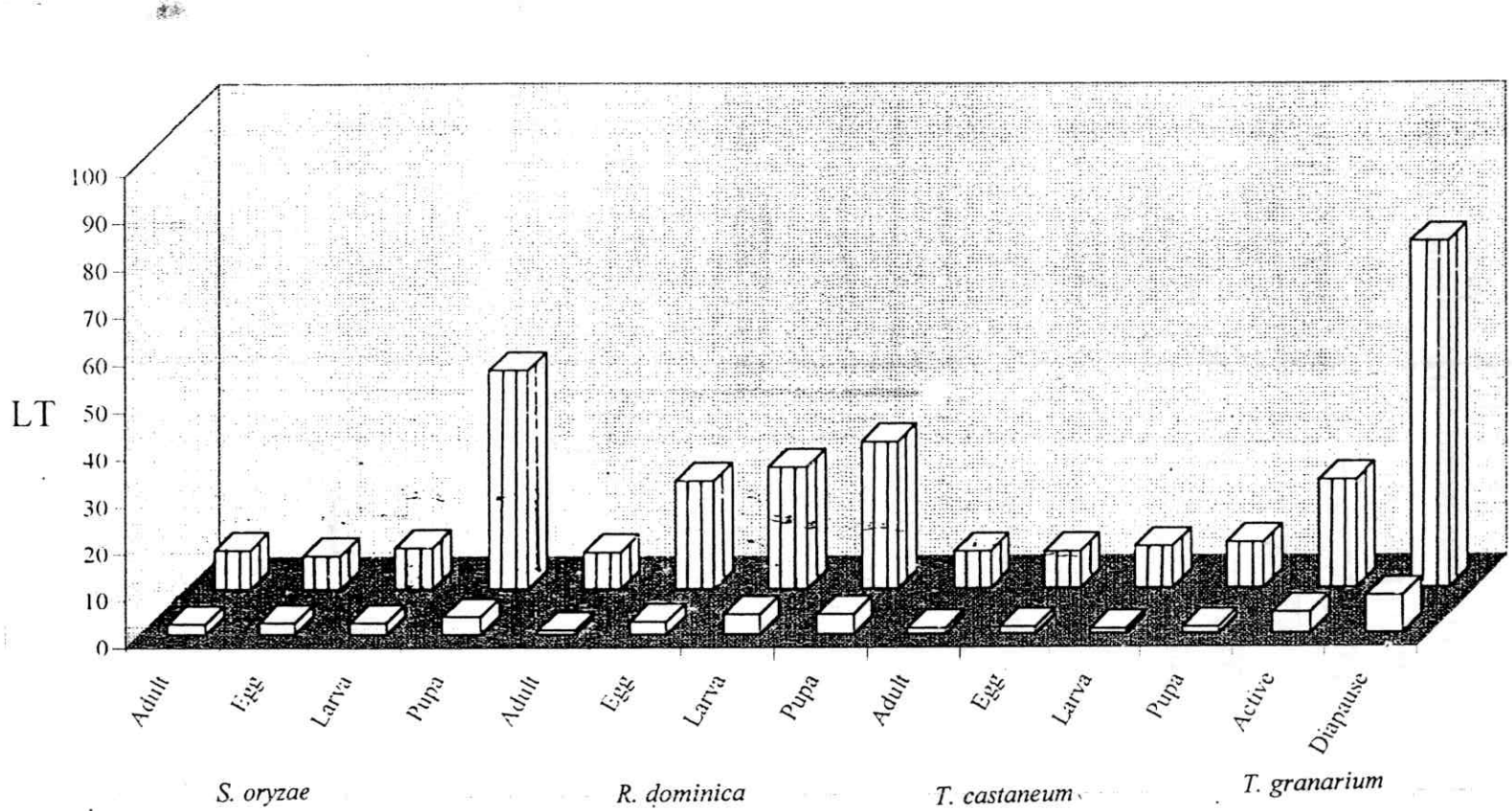


Fig (7): LT_{50} & LT_{99} for the tested stages of various insect species exposed to 80% CO_2 at 15 ± 2°C.

of this insect species was the most tolerant to the CA of 80 ± 5% CO_2 at 15 ± 2°C.

R. dominica:- The data show that the time needed to obtain 50% mortality for the adult, egg, larva and pupa of ***R. dominica*** was 0.8, 2.6, 4.2 and 4.2 days, respectively. To achieve 99% kill the recorded values were 7.7, 22.9, 25.8 and 31.1 days for the different stages, respectively. It was obvious that the adult stage of ***R. dominica*** was the most sensitive to this treatment.

T. castaneum:- The results show that the time needed to achieve 50% mortality for adult, egg, larva and pupa of ***T. castaneum*** was 1.2, 1.4, 1.0 and 1.3 days, respectively. To achieve 99% kill the obtained values were 7.8, 7.7, 8.8 and 9.6 days for the different stages, respectively.

T. granarium:- The time to achieve 50% kill was 4.4 and 7.9 days for the active and diapause larvae of ***T. granarium***, respectively. To obtain 99% mortality, the recorded values were 22.9 and 73.4 days for the active and diapause larvae, respectively. This result shows clearly that the diapause larvae were more tolerant to the CA of 80 ± 5% CO_2 at 15 ± 2°C than active one.

2. Efficacy of CA of 99% N_2 against the various insect species at different grain temperatures:

2.1. Efficacy of CA of 99% N_2 against the various insect species at 26 ± 2°C and 55 ± 5% R. H.:

The obtained results are listed in Table 6a and b.

2.1.1. Responses of the tested stages of various insect species to the CA of 99% N_2 at 26 ± 2°C and 55 ± 5% R. H. are given

Table (6a): Responses of the tested stages of various insect species to CA of 99% N_2 at 26 ± 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	
S. oryzae	Adult	25.0 ± 2.4	38.4 ± 2.3	80.7 ± 0.0	93.0 ± 3.3	99.0 ± 1.0	100	0
	Egg	22.0 ± 8.0	48.1 ± 0.0	63.3 ± 0.0	89.7 ± 0.2	98.0 ± 1.0	100	0
	Larva	13.2 ± 5.0	25.1 ± 1.7	33.3 ± 4.6	59.9 ± 6.8	81.7 ± 4.3	100	0
	Pupa	4.5 ± 1.9	16.1 ± 7.3	35.2 ± 6.8	52.7 ± 8.9	67.9 ± 2.2	76.0 ± 1.5	0
R. dominica	Adult	6.7 ± 0.0	21.7 ± 2.3	35.0 ± 2.4	60.0 ± 0.0	81.7 ± 2.3	89.0 ± 2.3	0
	Egg	39.3 ± 10.8	61.5 ± 3.0	75.0 ± 6.2	84.3 ± 1.2	88.6 ± 2.4	92.1 ± 1.3	0
	Larva	21.8 ± 3.8	30.4 ± 3.1	55.7 ± 0.2	68.6 ± 1.5	84.0 ± 5.3	93.9 ± 0.2	0
	Pupa	30.2 ± 9.0	44.0 ± 2.5	47.3 ± 0.6	51.2 ± 5.0	59.2 ± 3.1	88.8 ± 1.5	0
T. castaneum	Adult	0.0 ± 0.0	7.1 ± 1.9	12.0 ± 1.9	25.0 ± 2.4	60.0 ± 2.4	97.0 ± 2.0	0
	Egg	18.3 ± 2.9	33.3 ± 2.9	62.5 ± 3.5	82.5 ± 3.5	90.0 ± 0.0	98.0 ± 2.0	0
	Larva	41.7 ± 2.3	62.2 ± 1.9	78.4 ± 2.3	86.2 ± 1.9	96.0 ± 3.0	100	0
	Pupa	15.0 ± 2.4	41.7 ± 2.3	45.0 ± 2.4	61.7 ± 2.3	90.0 ± 1.3	96.0 ± 3.0	0
T. granarium larvae	Active	0.0 ± 0.0	1.1 ± 1.9	8.0 ± 3.9	30.0 ± 0.0	66.7 ± 0.0	89.0 ± 5.0	0
	Diapause	0.0 ± 0.0	0.0 ± 0.0	5.0 ± 2.4	15.6 ± 2.0	44.4 ± 2.0	78.0 ± 3.0	0

in Table 6a. The result show that insect mortalities increased with rising the exposure time.

S. oryzae:- At 2 day-exposure, mortality values were 25 ± 2.4; 22 ± 8, 13.2 ± 5 and 4.5 ± 1.9% for the adult, egg, larva and pupa of *S. oryzae*, respectively. These values reached 100% kill for the different stages except the pupa at 2 week-exposure, while the pupal mortality was 76 ± 1.5% only at this mentioned exposure period.

R. dominica:- The percentage mortalities recorded at 2 day-exposure for the adult, egg, larva and pupa of ***R. dominica*** were 6.7, 39.3 ± 10.8, 21.8 ± 3.8 and 30.2 ± 9%, respectively. These values increased to reach 89 ± 2.3, 92.1 ± 1.3, 93.9 ± 0.2 and 88.8 ± 1.5% at 2 week-exposure for the different stages, respectively.

T. castaneum:- Mortality data recorded at 2 day-exposure were 0.0, 18.3 ± 2.9, 41.7 ± 2.3 and 15 ± 2.4% for the adult, egg, larva and pupa of ***T. castaneum***. These percentages increased to 97 ± 2, 98 ± 2, 100 and 96 ± 3% at 2 weeks exposure period for the various stages, respectively.

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 to reach 89 ± 5 and 78 ± 3% at 2 week-exposure for the active and diapause larvae, respectively.

2.1.2. The lethal times and parameters of probit regression line estimates for the tested stages of various insect species, exposed to the CA of 99% N_2 at 26 ± 2°C and 55 ± 5% R. H. are shown in Table 6b & Fig (8).

Table (6b): Lethal times and parameters of probit regression line estimates for the tested stages of various insect species, exposed to CA of 99% N_2 at 26 ± 2°C and 55 ± 5 %R. H.

Insect species	Stage	Lethal times and their 95% confidence limits (days)			Slope ± SD	R
		LT_{50}	LT_{90}	LT_{99}		
S. oryzae	Adult	3.1 (2.8 – 3.5)	6.1 (5.1 – 7.3)	10.6 (7.9 – 14.2)	4.3929 ± 0.10	0.9923
	Egg	3.3 (2.9 – 3.8)	7.1 (5.8 – 8.6)	13.1 (9.3 – 18.4)	3.8871 ± 0.18	0.9813
	Larva	5.5 (4.7 – 6.5)	16.1 (10.8 – 24.0)	38.5 (20.0 – 73.8)	2.7594 ± 0.15	0.9702
	Pupa	7.1 (6.2 – 8.1)	20.0 (15.1 – 26.6)	46.7 (29.5 – 73.9)	2.8476 ± 0.05	09937
R. dominica	Adult	5.8 (5.1 – 6.5)	14.3 (11.5 – 17.8)	30.1 (21.2 – 42.7)	3.2360 ± 0.07	0.9935
	Egg	2.4 (1.8 – 3.1)	10.8 (7.9 – 14.8)	37.2 (19.5 – 70.9)	1.9469 ± 0.04	0.9890
	Larva	4.3 (3.7 – 4.9)	12.5 (9.8 – 15.9)	29.8 (19.7 – 45.0)	2.7606 ± 0.06	0.9930
	Pupa	4.7 (3.8 – 5.8)	28.7 (15.7 – 52.4)	126.0 (42.9 – 370.4)	1.6251 ± 0.40	0.8777
T. castaneum	Adult	7.6 (6.8 – 8.5)	14.1 (11.5 – 17.3)	23.2 (17.0 – 31.7)	4.8167 ± 1.04	0.9266
	Egg	3.9 (3.4 – 4.4)	9.1 (7.6 – 10.9)	18.3 (13.6 – 24.6)	3.4471 ± 0.05	0.9957
	Larva	2.4 (1.9 – 3.1)	7.4 (5.5 – 9.8)	18.3 (10.5 – 32.1)	2.6445 ± 0.04	0.9913
	Pupa	4.4 (3.9 – 4.9)	11.2 (9.1 – 13.9)	24.3 (17.0 – 34.8)	3.1197 ± 0.36	0.9656
T. granarium larvae	Active	8.6 (7.6 – 9.7)	14.2 (11.3 – 17.7)	21.3 (14.9 – 30.3)	5.9161 ± 0.03	0.9997
	Diapause	10.4 (9.0 – 12.0)	17.9 (13.3 – 24.0)	27.8 (17.6 – 44.0)	5.4286 ± 0.02	0.9970

R = Correlation coefficient of regression line.

SD = Standard deviation.

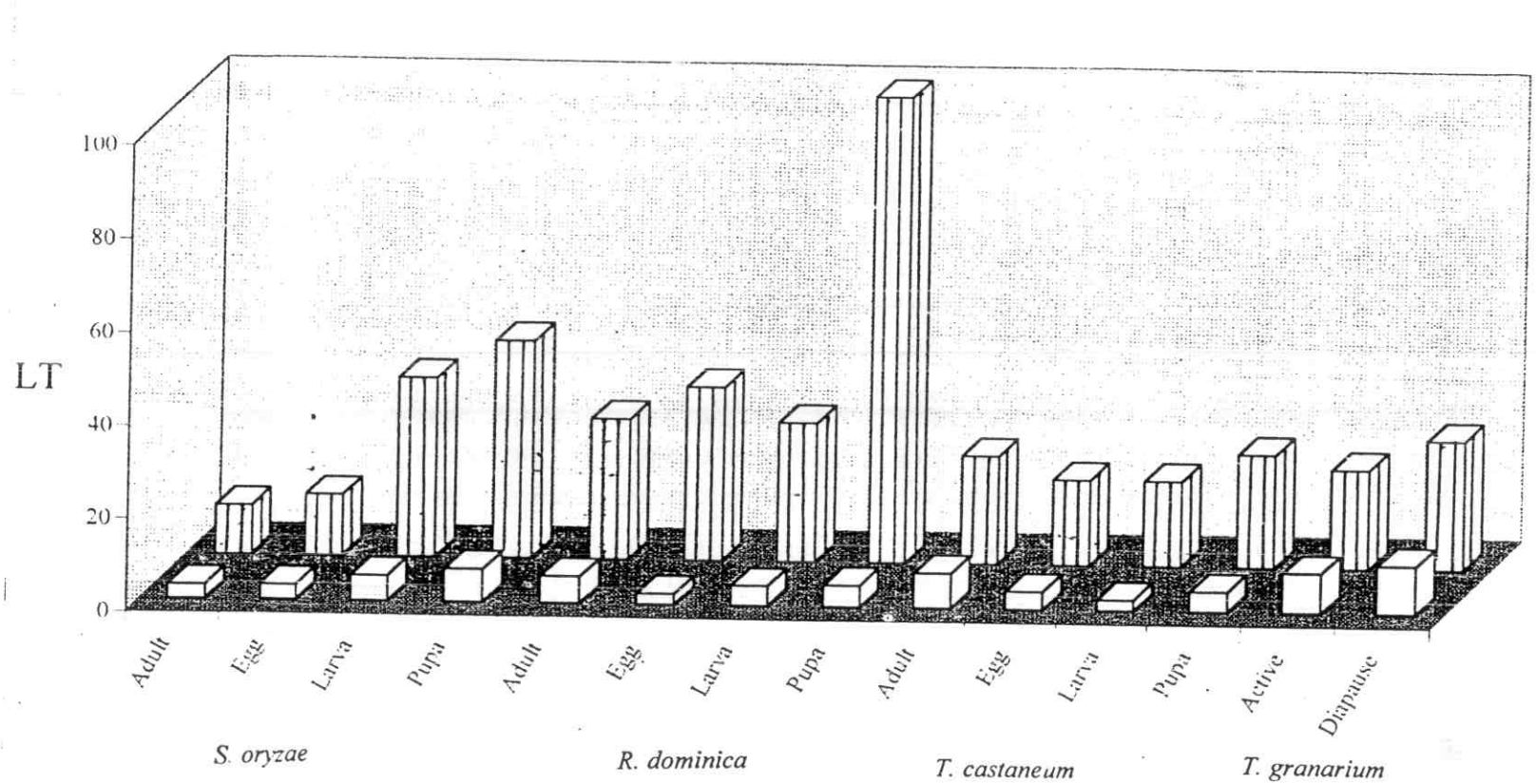


Fig (8): LT_{50} & LT_{99} for the tested stages of various insect species exposed to 99% N_2 at 26 ± 2°C.

S. oryzae:- The results indicate that, the time needed to obtain 50% mortality for the adult, egg, larva and pupa of ***S. oryzae*** was 3.1, 3.3, 5.5 and 7.1 days, respectively. To achieve 99% mortality the values were 10.6, 13.1, 38.5 and 46.7 days for the different stages, respectively. It was evident, that the adult and egg stages of this insect species were more susceptible to the CA of 99% N_2 at 26 ± 2°C than the larval and pupal stages.

R. dominica:- The data show that the time required to obtain 50% kill for the adult, egg, larva and pupa of ***R. dominica*** was 5.8, 2.4, 4.3 and 4.7 days, respectively. To achieve 99% mortality, the values were 30.1, 37.2, 29.8 and 126 days, respectively. This result indicates that the pupal stage of this insect species was the most tolerant to this treatment.

T. castaneum:- The results presented in Table 6b reveal that the time needed to obtain 50% mortality for the adult, egg, larva and pupa of ***T. castaneum*** was 7.6, 3.9, 2.4 and 4.4 days, respectively. To achieve 99% kill the values were 23.2, 18.3, 18.3 and 24.3 days, respectively. These values show that the susceptibility of the adult and pupal stages of this insect species to the CA of 99% N_2 at 26 ± 2°C was slightly less than that of the egg and larval stages.

T. granarium:- The recorded time to achieve 50% kill for the active and diapause larvae of ***T. granarium*** was 8.6 and 10.4 days, respectively. To obtain 99% mortalities, the values were 21.3 and 27.8 days for the active and diapause larvae, respectively. It was apparently, that the active larvae were more susceptible to this treatment than the diapause one.

2.2 Efficacy of CA of 99% N_2 against the various insect species at 21 ± 2°C and 55 ± 5% R. H.:

The obtained results are shown in Table 7a and b.

2.2.1 **Responses of the tested stages of various insect species to the CA of 99% N_2 at 21 ± 2°C and 55 ± 5% R.H.** are presented in Table 7a. The obtained percentage moralities indicate that their values increased with the increase of exposure period.

S. oryzae:- At 2 day-exposure, mortality values were 8.9 ± 5.1 , 37.7 ± 15.3, 23.3 ± 5.5 and 16.8 ± 1.6 % for the adult, egg, larva and pupa of ***S. oryzae***, respectively. These figures increased to reach 98 ± 2, 98.5 ± 1, 98.1 ± 0.6 and 66 ± 7.6 % at 2 week-exposure for the different stages, respectively.

R. dominica:- Mortality values recorded at 2 day-exposure were 8.9 ± 3.8, 10.1 ± 3.5, 26 ± 11.4 and 15.8 ± 2.3 % for the adult, egg, larva and pupa of ***R. dominica***, respectively. These values increased to 78.3 ± 6.7, 87.9 ± 2.6, 89 ± 1.7 and 79 ± 3.7% at two weeks exposure period for the different stages, respectively.

T. castaneum:- The data show that at 2 day-exposure, percentage moralities were 2.2 ± 1.9, 16.7 ± 2.9, 49 ± 3.9 and 32.2 ± 6.9% for the adult, egg, larva and papa of ***T. castaneum***, respectively. These values increased to 80.3 ± 3.4, 89 ± 5, 98 ± 2 and 90 ± 3% at 2 weeks exposure period for the various stages, respectively.

T. granarium:- At 5 day-exposure, the recorded moralities were 6.7 and 3.3 ± 3.4% for the active and diapause

Table (7a): Responses of the tested stages of various insect species to CA of 99% N_2 at 21± 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	
S. oryzae	Adult	8.9 ± 5.1	25.6 ± 5.1	76.7 ± 13.4	92.2 ± 1.9	98.0 ± 2.0	0.0
	Egg	37.7 ± 15.3	56.6 ± 11.7	86.1 ± 0.4	94.5 ± 4.1	98.5 ± 1.0	0.0
	Larva	23.3 ± 5.5	29.8 ± 4.7	58.4 ± 4.7	80.0 ± 0.1	98.1 ± 0.6	0.0
	Pupa	16.8 ± 1.6	28.3 ± 14.2	46.8 ± 11.0	59.0 ± 4.6	66.0 ± 7.6	0.0
R. dominic	Adult	8.9 ± 3.8	21.1 ± 1.9	33.3 ± 3.4	43.3 ± 8.8	78.3 ± 6.7	0.0
	Egg	10.1 ± 3.5	52.1 ± 16.1	75.1 ± 7.1	79.2 ± 3.6	87.9 ± 2.6	0.0
	Larva	26.0 ± 11.4	51.0 ± 3.0	63.0 ± 10.5	77.0 ± 12.5	89.0 ± 1.7	0.0
	Pupa	15.8 ± 12.3	19.8 ± 7.4	37.0 ± 12.8	47.5 ± 2.1	79.0 ± 3.7	0.0
T. castaneum	Adult	2.2 ± 1.9	2.2 ± 1.9	14.4 ± 2.0	56.0 ± 1.9	80.3 ± 3.4	0.0
	Egg	16.7 ± 2.9	22.5 ± 10.6	48.3 ± 2.9	61.7 ± 12.6	89.0 ± 5.0	0.0
	Larva	49.0 ± 3.9	72.0 ± 8.4	83.0 ± 3.2	90.0 ± 2.3	98.0 ± 2.0	0.0
	Pupa	32.2 ± 6.9	40.0 ± 6.4	56.0 ± 8.8	83.3 ± 3.3	90.0 ± 3.0	0.0
T. granarium larvae	Active	0.0 ± 0.0	6.7 ± 0.0	15.6 ± 5.1	38.9 ± 1.9	73.3 ± 3.4	0.0
	Diapause	0.0 ± 0.0	3.3 ± 3.4	9.6 ± 2.0	27.8 ± 1.9	66.7 ± 2.4	0.0

larvae of *T. granarium*, respectively. Percentage moralities increased to 73.3 ± 3.4 and 66.7 ± 2.4% at two weeks exposure for active and diapause larvae, respectively.

2.2.2.The lethal times and parameters of probit regression line estimates for the tested stages of various insect species, exposed to CA of 99% N_2 at 21 ± 2°C and 55 ± 5% R.H. are presented in Table 7b & Fig (9).

S. oryzae:- The results show that the time required to obtain 50% kill for the adult, egg, larva and pupa of ***S. oryzae*** was 5.7, 3.9, 5.5 and 8.4 days, respectively. To achieve 99% mortality, the values were 15.3, 15.5, 20.2 and 99.8 days for the various stages, respectively. This result clearly reveals that the pupal stage of ***S. oryzae*** was the most tolerant to the CA of 99% N_2 at 21 ± 2°C.

R. dominica:- The recorded time to obtain 50% mortality was 9.3, 5.7, 5.1 and 8.8 days for the adult, egg, larva and pupa of ***R. dominica***, respectively. To achieve 99% mortality, values were 56.8, 25.7, 36.8 and 67.8 days for the different stages, respectively. It was evident that the adult and pupal stages were more tolerant to the treatment than the other insect stages.

T. castaneum:- The time required to achieve 50% kill for the adult, egg, larva and pupa of ***T. castaneum*** was 10, 7.1, 3.2 and 5.2 days, respectively. To achieve 99% mortality, the values were 22.7, 36.8, 19.7 and 34.7 days for the different stages, respectively. This result indicates that the egg and pupa of ***T. castaneum*** were more tolerant to the CA of 99% N_2 at 21 ± 2°C than the other stages.

Table (7b): Lethal times and parameters of probit regression line estimates for the tested stages of various insect species, exposed to CA of 99% N_2 at 21 ± 2°C and 55 ± 5 %R. H.

Insect species	Stage	Lethal times and their 95% confidence limits (days)			Slope ± SD	R
		LT_{50}	LT_{90}	LT_{99}		
S. oryzae	Adult	5.7 (5.1 – 6.3)	9.8 (8.4 – 11.4)	15.3 (12.1 – 19.4)	5.3759 ± 0.22	0.9864
	Egg	3.9 (3.3 – 4.6)	8.4 (6.9 – 10.1)	15.5 (11.0 – 22.0)	3.8805 ± 0.08	0.9894
	Larva	5.5 (4.9 – 6.2)	11.3 (9.3 – 13.8)	20.2 (14.5 – 28.0)	4.1463 ± 0.52	0.9486
	Pupa	8.4 (6.8 – 10.3)	32.8 (17.5 – 61.4)	99.8 (35.0 – 285.0)	2.1636 ± 0.02	0.9905
R. dominica	Adult	9.3 (7.8 – 11.0)	25.2 (16.5 – 38.3)	56.8 (29.1 – 111.1)	2.9535 ± 0.15	0.9697
	Egg	5.7 (4.9 – 6.5)	13.0 (10.4 – 16.3)	25.7 (17.4 – 38.0)	3.5346 ± 0.33	0.9551
	Larva	5.1 (4.3 – 6.1)	15.2 (11.0 – 21.1)	36.8 (20.3 – 66.6)	2.7195 ± 0.01	0.9979
	Pupa	8.8 (7.3 – 10.6)	27.1 (16.7 – 43.8)	67.8 (31.1 – 147.8)	2.6200 ± 0.22	0.9463
T. castaneum	Adult	10.0 (8.9 – 11.3)	15.7 (12.7 – 19.6)	22.7 (16.2 – 31.9)	6.5633 ± 0.04	0.9962
	Egg	7.1 (6.1 – 8.1)	17.5 (12.9 – 23.8)	36.8 (22.3 – 60.7)	3.2447 ± 0.24	0.9609
	Larva	3.2 (2.5 – 4.1)	8.7 (6.9 – 11.0)	19.7 (12.1 – 32.0)	2.9457 ± 0.06	0.9866
	Pupa	5.2 (4.4 – 6.1)	14.8 (10.8 – 20.3)	34.7 (19.7 – 61.2)	2.8147 ± 0.16	0.9638
T. granarium larvae	Active	10.9 (9.2 – 12.9)	20.3 (14.0 – 29.5)	33.7 (18.9 – 60.3)	4.7384 ± 0.04	0.9915
	Diapause	12.2 (10.2 – 14.7)	22.0 (14.7 – 32.6)	35.4 (19.4 – 64.6)	5.0282 ± 0.06	0.9894

R = Correlation coefficient of regression line.

SD = Standard deviation.

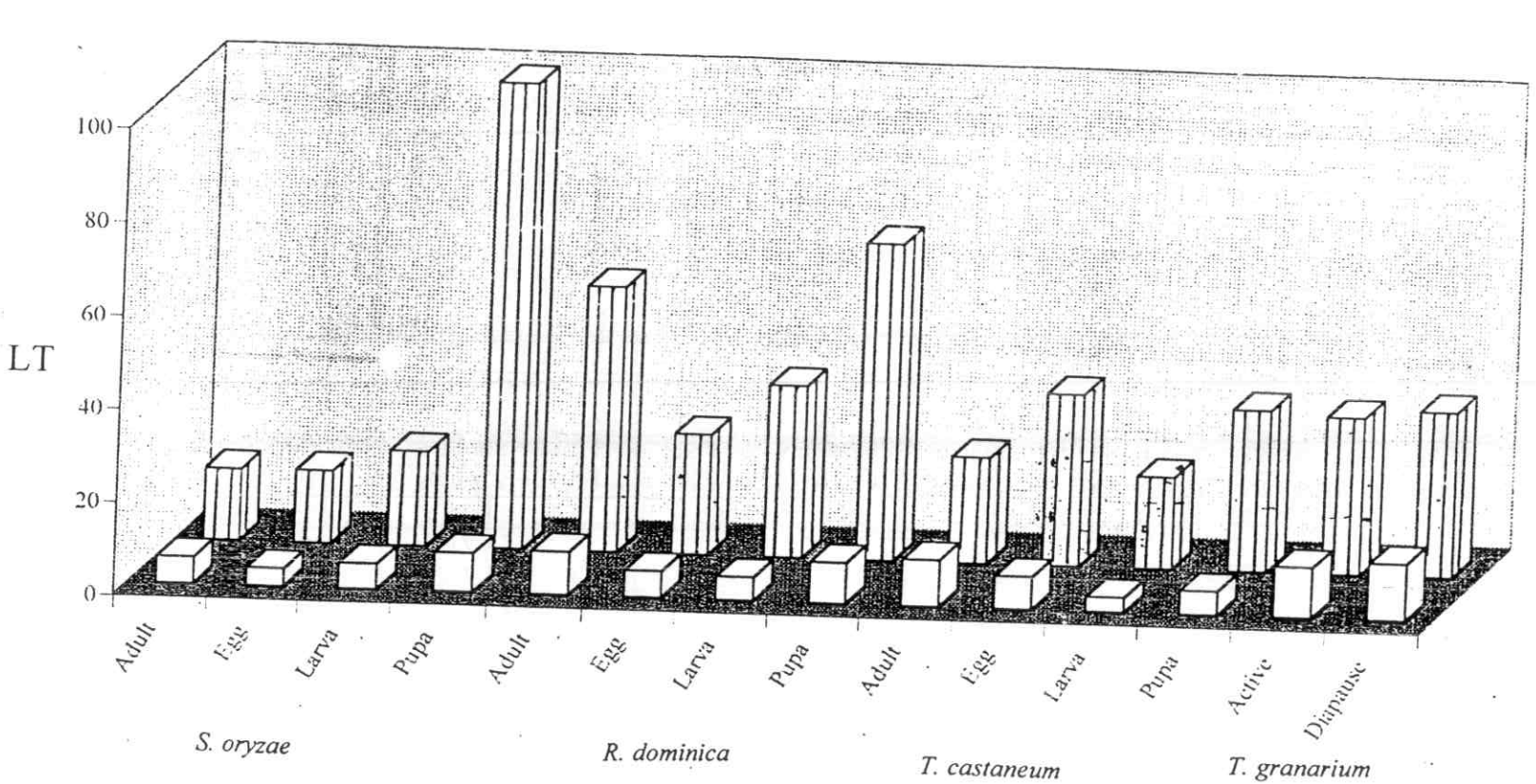


Fig (9): LT_{50} & LT_{99} for the tested stages of various insect species exposed to 99% N_2 at 21 ± 2°C.

T. granarium:- The results indicate that, the time needed to achieve 50% mortality for the active and diapause larvae of *T. granarium* was 10.9 and 12.2 days, respectively. To achieve 99% kill, the values were 33.7 and 35.4 days, respectively. This result shows no great difference in the susceptibility of the active and diapause larvae to the CA of 99% N_2 at 21 ± 2°C.

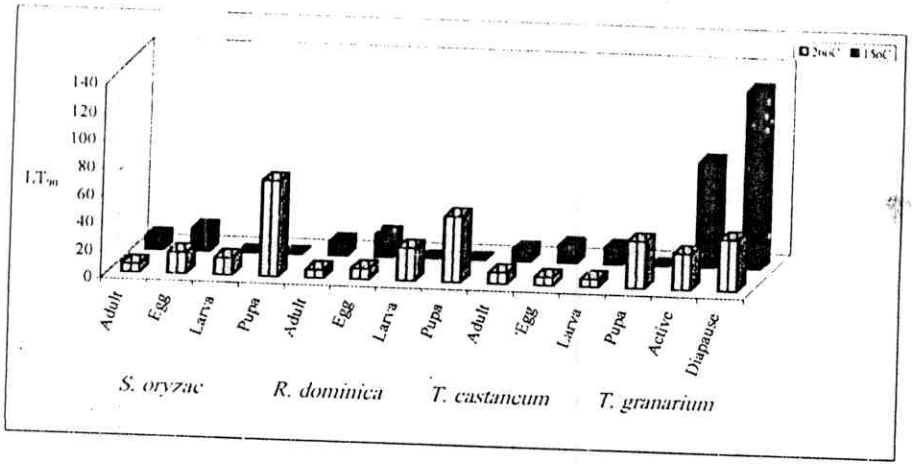
Table (7c) and Figures (10) show the time required for achieving 90% mortality for the various stages of tested insects at different treatments. The results revealed that the susceptibility of the adults and immature stages of ***S. oryzae***, ***R. dominica*** and ***T. castaneum*** as well as active and diapausing larvae of ***T. granarium*** to the CA of CO_2 was increased with rising the temperature and CO_2-concentration of the atmosphere. Also, the susceptibility of the adults and nearly of all the immature stages of the above mentioned test insects to CA of 99% N_2 was less at 21°C than at 26°C with the exception of the larvae of ***S. oryzae*** and the pupae of ***R. dominica***. Generally, the adults of the insects were more susceptible to various treatments than their immature stages at various temperatures. The diapause larvae of ***T. granarium*** were more tolerant to the different treatments than active one.

The pupae of the insects were highly tolerant to the different treatments than the other stages. Also, it was obvious, that the pupae of ***S. oryzae*** were the most tolerant pupal stage to the various treatments.

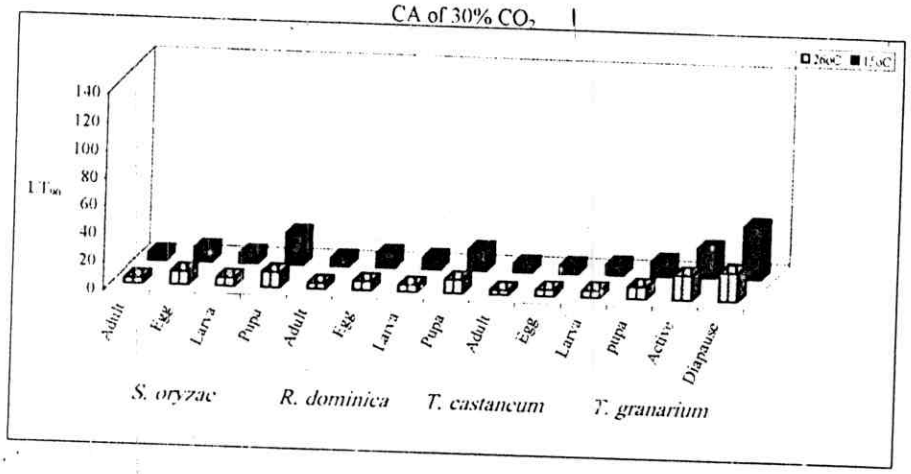
These differences in the susceptibility of the different stages are known to be due to the difference in the rate of metabolism of the various stages.

Table (7c): The time required for achieving 90% mortalities for the various stages of tested insects at different treatments

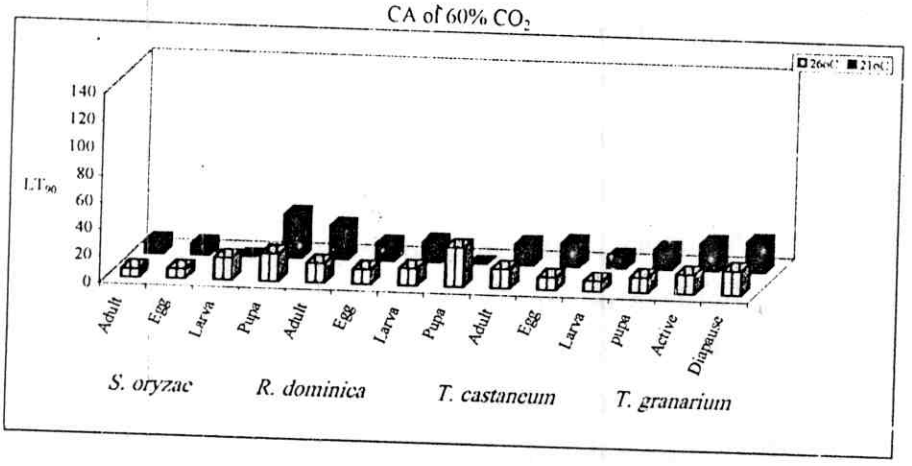
Insect species	stage	Time (days) to achieve 90% mortality at various treatments					
		CA of 30% CO_2		CA of 60% CO_2		CA of 99% N_2	
		26°C	15°C	26°C	15°C	26°C	21°C
S. oryzae	Adult	6.4	10.2	4.2	6.1	6.1	9.8
	Egg	15.7	16.9	9.6	10.4	7.1	8.4
	Larva	12.7	11.7 *	6.1	7.5	16.1	11.3 *
	Pupa	69.8	41.9 *	11.2	22.7	20.0	32.8
R. dominica	Adult	6.1	10.4	4.3	6.1	14.3	25.2
	Egg	7.8	16.9	6.5	10.8	10.8	13.0
	Larva	24.0	13.8 *	5.0	8.6	12.5	15.2
	Pupa	48.1	34.7 *	10.1	15.3	28.7	27.1 *
T. castaneum	Adult	8.2	9.0	3.5	6.5	14.1	15.7
	Egg	6.0	13.3	4.5	6.3	9.1	17.5
	Larva	5.7	12.3	5.1	7.8	7.4	8.7
	Pupa	34.4	17.4 *	8.7	11.0	11.2	14.8
T. granarium larvae	Active	26.1	76.7	18.1	21.3	14.2	20.3
	Diapause	37.3	128.2	21.0	38.1	17.9	22.0



CA of 30% CO_2



CA of 60% CO_2



CA of 99% N_2

0): Time to obtain 90% mortality for the different stages of stored product insects at various treatment

Data obtained in Table (7c) by exposing mature and immature stages of the insect species under study to the CA of 30% CO_2 at higher temperature of 26°C suggest that adults of ***S. oryzae*** were the most susceptible, followed by larvae, eggs and pupae. In case of ***R. dominica***, the adults were also the most susceptible, followed by eggs, larvae and pupae. As for ***T. castaneum***, the larvae were the most susceptible, followed by eggs, adults and pupae. Active larvae of ***T. granarium*** were more susceptible than diapause one

Meanwhile, by exposing the mature and immature stages of the insects to the CA of 99% N_2 at 26°C, the time to 90% kill indicate that adults of ***S. oryzae*** were the most susceptible, followed by eggs, larvae and pupae. For ***R. dominica***, the eggs were the most susceptible stage, followed by larvae, adults and pupae. As for ***T. castaneum***, larvae were the most susceptible stage, followed by eggs, pupae and adults. However, diapause larvae of ***T. granarium*** were more tolerant to the CA of 99% N_2 than active one. Furthermore, increasing the temperature resulted in increased insect mortalities at the different treatments.

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 cautella*** 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.

Also, the obtained results on the efficacy of CA of 99% N_2 against the tested insects coincide with those obtained by **Reichmuth, 1986; Navarro and Jay, 1987; Adler, 1990;**

Reichmuth and Ofuya, 1992; Hashem *et al.*, 1993 and EL-Lakwah *et al.*, 1997.

3- Efficacy of phosphine against the various insect species at 26 ± 2°C and 55 ± 5% R.H.

The obtained results on the efficacy of 100 ppm phosphine against various insect species are given in Tables 8a and b.

S. oryzae:- The recorded percentage mortalities for the various stages of *S. oryzae* (Table 8a) show that their values increased with the increase of the exposure period. At 1-day-exposure, mortality values were 54.4 ± 5.1, 30.4 ± 1, 46.2 ± 0.4 and 44.3 ± 1% for the adult, egg, larva and pupa, respectively. Complete kill was obtained for the adult and larval stages at 5 day-exposure, while mortality values of egg and pupa were only 99 ± 1% and 95.3 ± 0.3 %, respectively.

R. dominica:- The obtained percentage mortalities at 1 day-exposure were 47.5 ± 3.9, 50.8 ± 7, 53.7 ± 4.5 and 43.9 ± 3.4% for the adult, egg, larva and pupa of *R. dominica*, respectively. Complete kill was obtained at 5 day-exposure for the various stages except the pupal stage which its mortality was 97 ± 3% only at this exposure period.

T. castaneum:- Percentage mortalities at 1 day-exposure were 60 ± 7.9, 43 ± 6, 50.2 ± 5.1 and 40 ± 6.7% for the adult, egg, larva and pupa of *T. castaneum*, respectively. These values increased at 5 day-exposure to 100, 99.9 ± 1, 100 and 99 ± 1% for the various stages, respectively.

Table (8a): Responses of the tested stages of various insect species to 100 ppm of phosphine at 26 ± 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	54.4 ± 5.1	98.0 ± 0.0	99.9 ± 0.3	100	100	0.0
	Egg	30.4 ± 1.0	78.1 ± 5.9	90.8 ± 0.8	99.0 ± 1.0	100	0.0
	Larva	46.2 ± 0.4	87.2 ± 2.0	95.0 ± 1.9	100	100	0.0
	Pupa	44.3 ± 1.0	66.9 ± 3.3	86.3 ± 4.7	95.3 ± 0.3	100	0.0
R. dominica	Adult	47.5 ± 3.9	74.4 ± 2.0	98.0 ± 1.3	100	100	0.0
	Egg	50.8 ± 7.0	89.8 ± 1.9	97.8 ± 2.5	100	100	0.0
	Larva	53.7 ± 4.5	83.5 ± 4.5	98.7 ± 2.3	100	100	0.0
	Pupa	43.9 ± 3.4	68.2 ± 3.0	83.1 ± 1.7	97.0 ± 3.0	100	0.0
T. castaneum	Adult	60.0 ± 7.9	98.0 ± 2.0	99.0 ± 1.0	100	100	0.0
	Egg	43.0 ± 6.0	69.0 ± 7.0	88.0 ± 3.5	99.9 ± 1.0	100	0.0
	Larva	50.2 ± 5.1	73.0 ± 5.0	89.0 ± 6.0	100	100	0.0
	Pupa	40.0 ± 6.7	69.0 ± 3.0	87.0 ± 3.0	99.0 ± 1.0	100	0.0
T. granarium larvae	Active	12.2 ± 1.9	53.3 ± 3.4	88.0 ± 3.0	99.0 ± 1.0	100	0.0
	Diapause	6.7 ± 3.4	31.1 ± 1.9	66.0 ± 9.0	90.0 ± 5.0	100	0.0

T. granarium:- At 1 day-exposure, the recorded mortalities were 12.2 ± 1.9 and 6.7 ± 3.4 % for the active and diapause larvae of ***T. granarium***. These percentages increased to 99 ± 1% and 90 ± 5% at 5 day-exposure for the active and diapause larvae, respectively.

The lethal times and parameters of probit regression line estimates for the tested stages of various insect species, exposed to 100 ppm phosphine at grain temperature 26 ± 2°C and 55 ± 5% R.H. are listed in Table 8b & Fig (11).

S. oryzae:- The results show that the time needed to obtain 50% kill for the various stages of ***S. oryzae*** was 0.9, 1.3, 1.0 and 1.2 days for the adult, egg, larva and pupa, respectively. To achieve 99% mortality, the values increased to 2.4, 5.1, 4.4 and 9.1 days for the different stages, respectively. It was evident that the pupal stage of ***S. oryzae*** was the most tolerant to the treatment of 100 ppm phosphine at 26 ± 2°C.

R. dominica:- Results in Table 8b show that the time needed to obtain 50% mortality for the adult, egg, larva and pupa of ***R. dominica*** was 1.2, 1.1, 1.1 and 1.2 days, respectively. To achieve 99% kill, the values increased to 3.2, 3, 3, and 8.1 days for the different stages, respectively. This result reveals that the pupal stage of ***R. dominica*** was the most tolerant to phosphine at 26 ± 2°C.

T. castaneum:- The lethal time values recorded for 50% mortality were 0.9, 1.3, 1.1 and 1.3 days for the adult, egg, larva and pupa of ***T. castaneum***, respectively. To achieve 99% kill, these values increased to 2.6, 4.3, 5.8 and 5.7 days for the different stages, respectively. It was obvious, that the adults of ***T.***

Table (8b): Lethal times and parameters of probit regression line estimates for the tested stages of various insect species, exposed to 100 ppm of phosphine at 26 ± 2°C and 55 ± 5 %R. H.

Insect species	Stage	Lethal times and their 95% confidence limits (days)			Slope ± SD	R
		LT_{50}	LT_{90}	LT_{99}		
S. oryzae	Adult	0.9 (0.7 – 1.2)	1.5 (1.1 – 2.1)	2.4 (1.3 – 4.5)	5.2746 ± 0.21	0.9859
	Egg	1.3 (1.1 – 1.7)	2.8 (2.1 – 3.7)	5.1 (3.1 – 8.2)	4.0052 ± 0.01	0.9985
	Larva	1.0 (0.4 – 2.6)	2.3 (0.9 – 6.2)	4.4 (0.7 – 28.6)	3.6953 ± 0.01	0.9964
	Pupa	1.2 (0.8 – 1.7)	3.7 (2.4 – 5.6)	9.1 (4.0 – 20.8)	2.6525 ± 0.03	0.9920
R. dominica	Adult	1.2 (1.0 – 1.4)	2.1 (1.7 – 2.5)	3.2 (2.3 – 4.5)	5.4564 ± 0.57	0.9652
	Egg	1.1 (0.9 – 1.3)	1.9 (1.5 – 2.4)	3.0 (2.1 – 4.4)	5.1628 ± 0.20	0.9857
	Larva	1.1 (0.9 – 1.3)	1.9 (1.5 – 2.4)	3.0 (2.1 – 4.4)	5.2250 ± 0.32	0.9784
	Pupa	1.2 (0.9 – 1.7)	3.5 (2.4 – 5.2)	8.1 (3.8 – 17.1)	2.8614 ± 0.07	0.9842
T. castaneum	Adult	0.9 (0.6 – 1.2)	1.6 (1.2 – 2.1)	2.6 (1.6 – 4.4)	4.7578 ± 0.17	0.9859
	Egg	1.3 (1.1 – 1.6)	2.5 (2.0 – 3.2)	4.3 (2.9 – 6.4)	4.5029 ± 0.65	0.9435
	Larva	1.1 (0.8 – 1.5)	2.8 (2.0 – 3.8)	5.8 (3.1 – 10.8)	3.2744 ± 0.14	0.9755
	Pupa	1.3 (1.0 – 1.7)	2.9 (2.2 – 4.0)	5.7 (3.3 – 9.9)	3.6280 ± 0.14	0.9806
T. granarium larvae	Active	1.8 (1.5 – 2.1)	3.2 (2.5 – 4.1)	5.1 (3.5 – 7.5)	5.0448 ± 0.04	0.9967
	Diapause	2.4 (2.0 – 2.9)	5.1 (3.7 – 7.0)	9.2 (5.5 – 15.6)	4.0333 ± 0.03	0.9967

R = Correlation coefficient of regression line.

SD = Standard deviation.

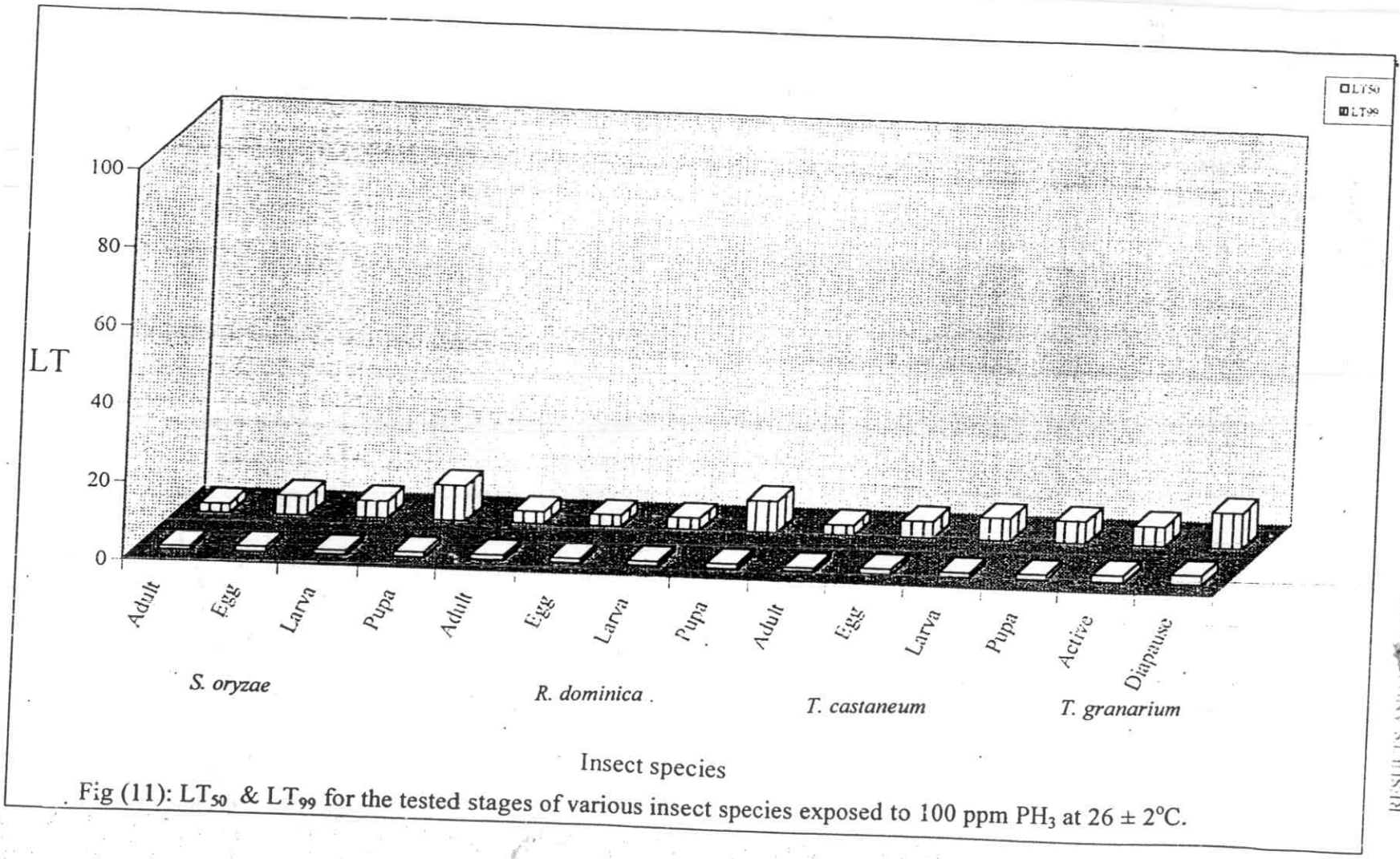


Fig (11): LT_{50} & LT_{99} for the tested stages of various insect species exposed to 100 ppm PH_3 at 26 ± 2°C.

castaneum were more susceptible to phosphine treatment than the other inset stages.

T. granarium:- The lethal time values registered for the active and diapause larvae of *T. granarium* for achieving 50% kill were 1.8 and 2.4 days, respectively. To achieve 99% mortality these values increased to 5.1 and 2.2 days, respectively. This result shows that the diapause larvae of *T. granarium* were more tolerant to phosphine than the active one.

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.**

4. Efficacy and combined action of phosphine with carbon dioxide against the tested insect species at varying grain temperatures:

4.1. Efficacy and combined action of phosphine (100 ppm) with 30 ± 5% CO_2 at grain temperatures of 26 ± 2°C and 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 at 26 ± 2°C and varying exposure periods are given in Tables 9, 10, 11 and 12.

The results recorded in Table 9 & Fig 12 show the obtained data at 1-day exposure period. The results indicate clearly that percentage moralities resulted from the combinations

Table (9): Efficacy and combined action of 100 ppm phosphine with 30 ± 5 % carbon dioxide to the tested stages of various insect species at grain temperature of 26 ± 2°C and 55 ± 5 % R. H. after 1 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	54.4	28.6	93.3	12.4	d
	Egg	30.4	23.6	69.5	28.7	s
	Larva	46.2	32.8	80.2	1.5	d
	Pupa	44.3	18.7	71.9	14.1	d
R. dominica	Adult	47.5	8.5	92.2	64.6	s
	Egg	50.8	28.2	95.8	20.6	s
	Larva	53.7	35.3	83.1	-6.6	d
	Pupa	43.9	15.1	83.3	41.2	s
T. castaneum	Adult	60.0	3.3	90.0	42.2	s
	Egg	43.0	26.7	60.0	-13.9	d
	Larva	50.2	35.6	80.0	-5.9	d
	Pupa	40.0	25.6	63.0	-4.0	d
T. granarium larvae	Active	12.2	6.7	32.2	70.3	s
	Diapause	6.7	3.3	15.6	56.0	s

d = additive effect

s = synergistic effect

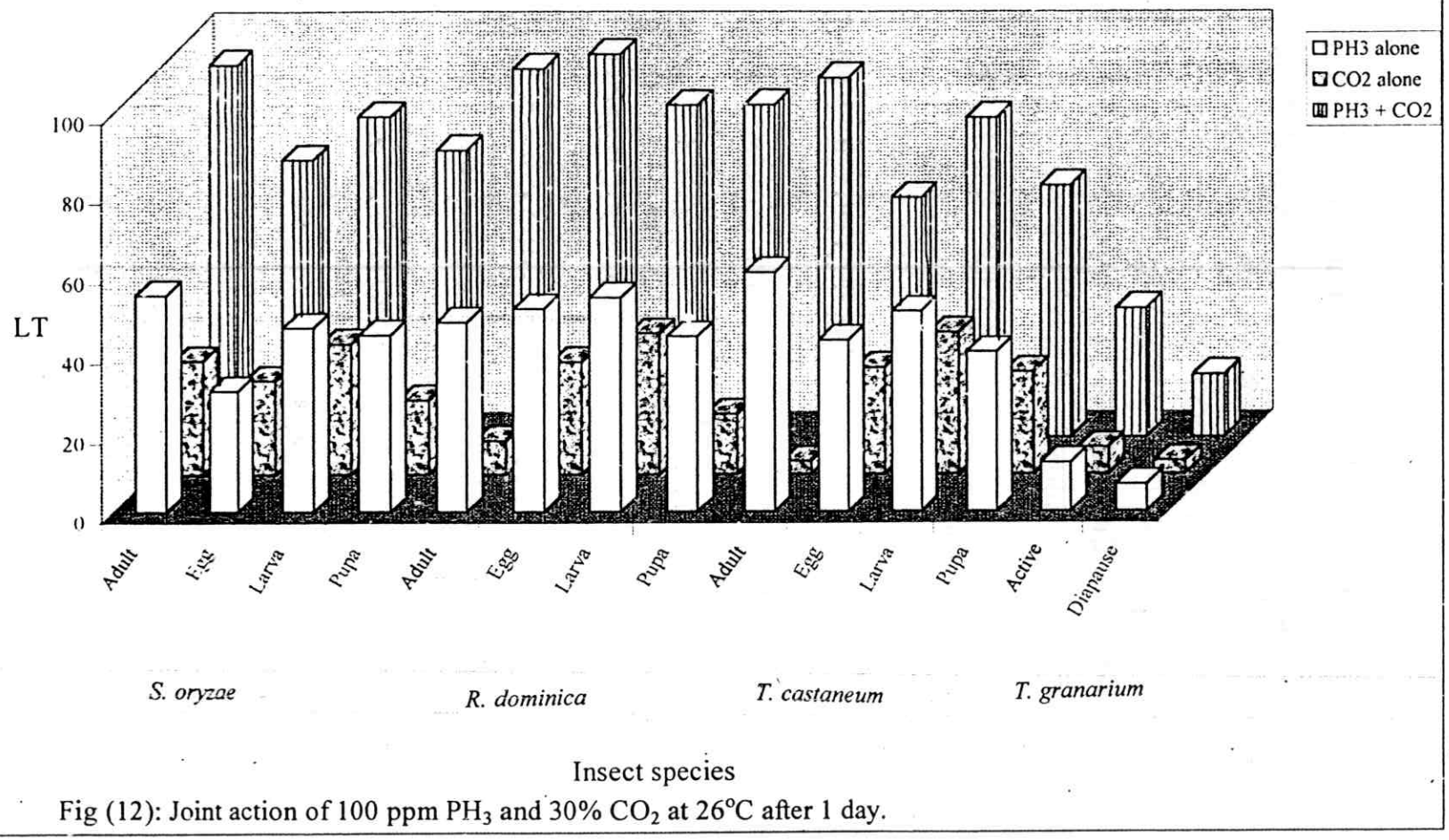


Fig (12): Joint action of 100 ppm PH_3 and 30% CO_2 at 26°C after 1 day.

of phosphine and carbon dioxide were obviously greater than those obtained from each gas alone.

Co-Toxicity values resulted from the mixture of 100 ppm phosphine plus 30 ± 5% carbon dioxide showed additive/or synergistic effects for the tested stages of various insect species.

Co-toxicity values of the same mixture at two days exposure period showed with the different stages of ***S. oryzae***, ***R. dominica*** and ***T. castaneum*** pronounced additive effect, but in case of active and diapause larvae of ***T. granarium*** a synergistic effect was noticed (Table, 10 & Fig. 13).

The results of the same mixture of phosphine and carbon dioxide at 3 days exposure periods are summarized in Table 11 & Fig 14. 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 the exception of the diapause larvae of ***T. granarium***, where a synergistic effect was observed.

After 5 days-exposure, the results given in Table 12 & Fig 15 indicate additive effects for the mixture with the different stages of all tested insect species.

4.2. Efficacy and combined action of 100 ppm phosphine with 60 ± 5% CO_2 at grain temperature of 14 ± 1°C:

Results of the efficacy and combined action of 100 ppm phosphine with 60 ± 5% CO_2 to the tested stages of various insect species at grain temperature of 14 ± 1°C and 55 ± 5% R.H. after 2 days exposure period are presented in Table (13) & Fig (16). It was evident that the percentage mortalities of the insects

Table (10): Efficacy and combined action of 100 ppm phosphine with 30 ± 5 % carbon dioxide to the tested stages of various insect species at grain temperature of 26 ± 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
		PH3 alone	CO2 alone	PH3 + CO2		
S. oryzae	Adult	98.0	31.1	100	0.0	d
	Egg	78.1	31.1	98.2	-1.8	d
	Larva	87.2	41.8	91.8	-8.2	d
	Pupa	66.9	29.6	85.7	-11.2	d
R. dominic	Adult	74.4	10.0	100	15.6	d
	Egg	89.8	37.0	98.9	-1.1	d
	Larva	83.5	31.6	96.1	-3.9	d
	Pupa	68.2	15.8	89.2	6.2	d
T. castaneum	Adult	98.0	5.3	100	0.0	d
	Egg	69.0	40.0	98.0	-2.0	d
	Larva	73.0	43.0	99.0	-1.0	d
	Pupa	69.0	37.8	87.0	-13.0	d
T. granarium larvae	Active	53.3	12.2	90.0	37.4	s
	Diapause	31.1	10.0	76.0	84.9	s

d = additive effect

s = synergistic effect

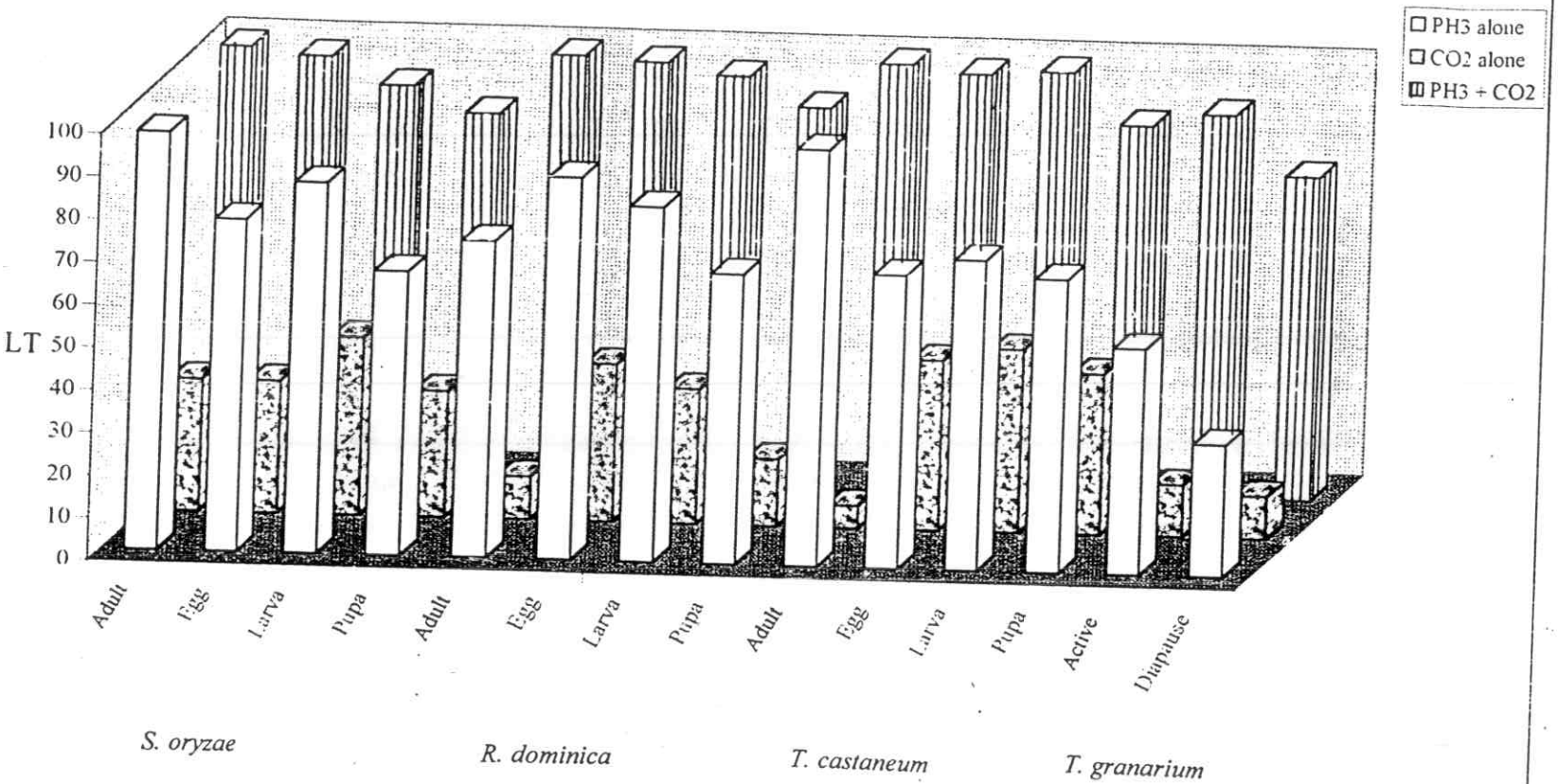


Fig (13): Joint action of 100 ppm PH_3 and 30% CO_2 at 26°C after 2 days.

Table (11): Efficacy and combined action of 100 ppm phosphine with 30 ± 5 % carbon dioxide to the tested stages of various insect species at grain temperature of 26 ± 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	99.9	62.2	100	0.0	d
	Egg	90.8	50.4	98.5	-1.5	d
	Larva	95.0	52.6	99.3	-0.7	d
	Pupa	86.3	32.5	99.3	-0.7	d
R. dominica	Adult	98.0	50.0	100	0.0	d
	Egg	97.8	62.0	100	0.0	d
	Larva	98.7	36.9	100	0.0	d
	Pupa	83.1	18.4	95.1	-4.9	d
T. castaneum	Adult	99.0	20.0	100	0.0	d
	Egg	88.0	63.0	100	0.0	d
	Larva	89.0	61.7	100	0.0	d
	Pupa	87.0	49.0	100	0.0	d
T. granarium	Active	88.0	18.9	100	0.0	d
larvae	Diapause	66.0	11.1	100	29.7	s

d = additive effect

s = synergistic effect

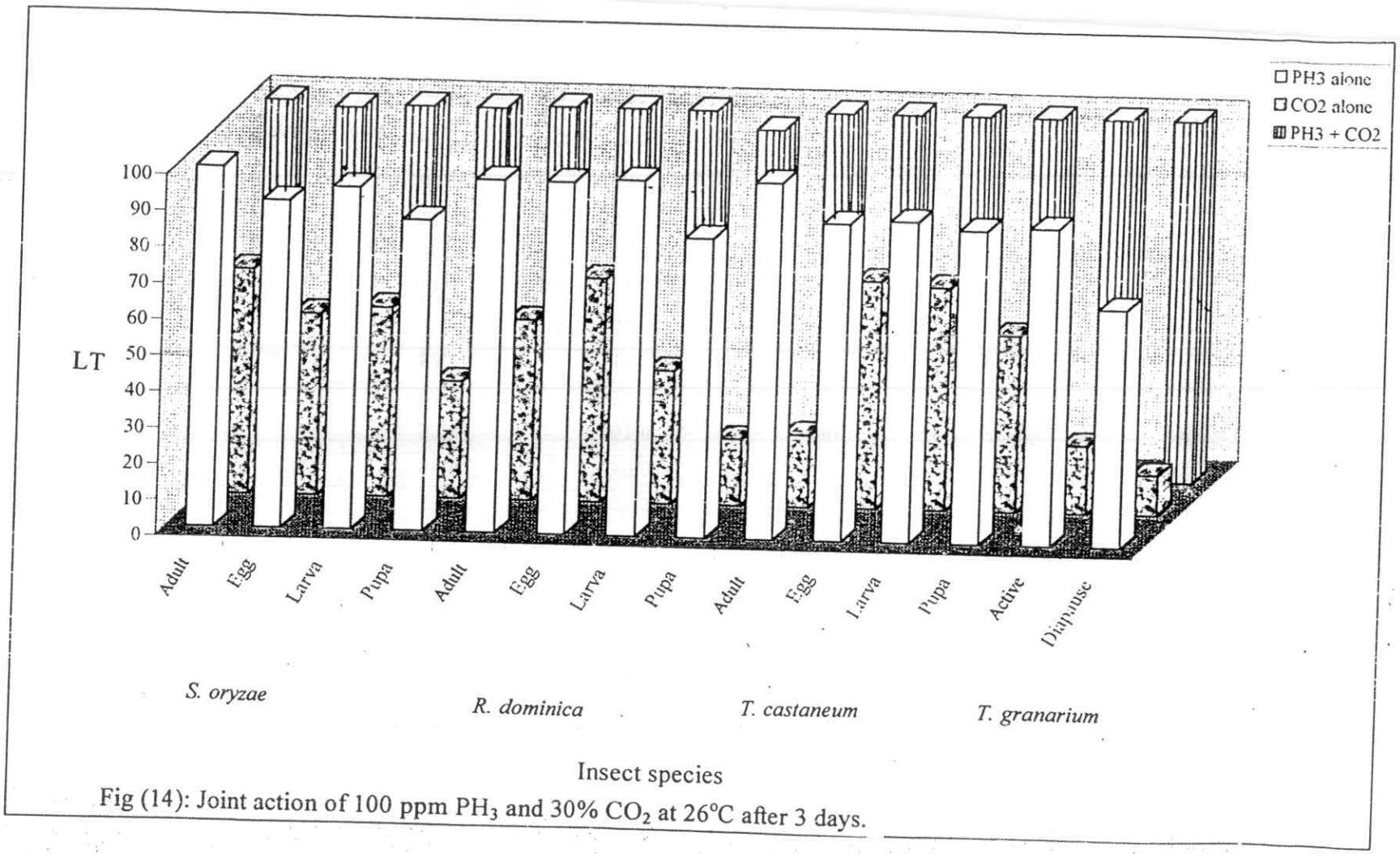


Fig (14): Joint action of 100 ppm PH_3 and 30% CO_2 at 26°C after 3 days.

Table (12): Efficacy and combined action of 100 ppm phosphine with 30 ± 5 % carbon dioxide to the tested stages of various insect species at grain temperature of 26 ± 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	80.0	100	0.0	d
	Egg	99.0	59.4	99.7	-0.3	d
	Larva	100	63.2	100	0.0	d
	Pupa	95.3	35.5	99.6	-0.4	d
R. dominica	Adult	100	91.1	100	0.0	d
	Egg	100	64.0	100	0.0	d
	Larva	100	38.6	100	0.0	d
	Pupa	97.0	28.6	100	0.0	d
T. castaneum	Adult	100	36.7	100	0.0	d
	Egg	99.9	85.0	100	0.0	d
	Larva	100	83.3	100	0.0	d
	Pupa	99.0	53.0	100	0.0	d
T. granarium larvae	Active	99.0	27.8	100	0.0	d
	Diapause	99.0	15.6	100	0.0	d

d = additive effect

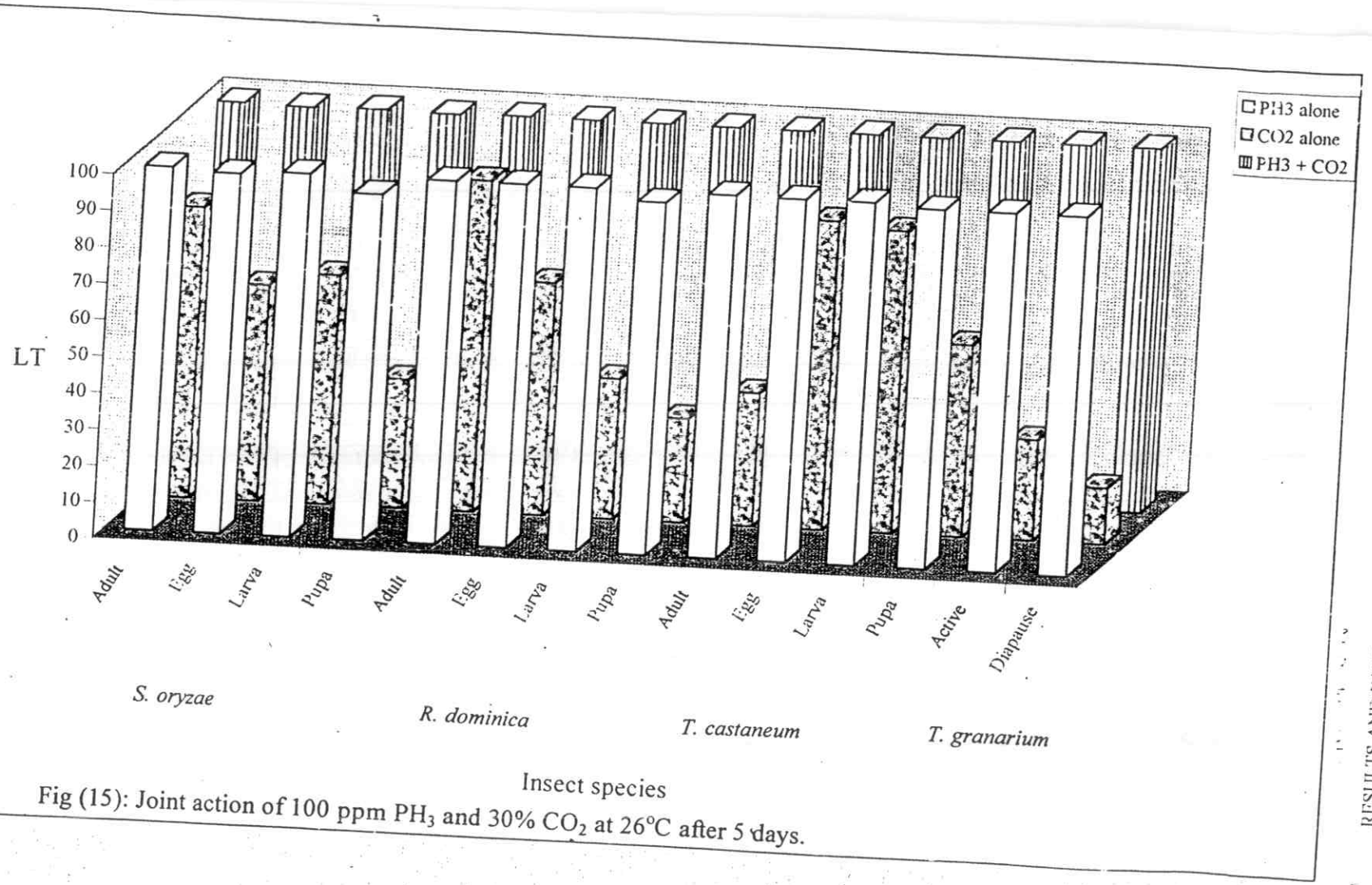


Fig (15): Joint action of 100 ppm PH_3 and 30% CO_2 at 26°C after 5 days.

Table (13): Efficacy and combined action of 100 ppm phosphine with 60 ± 5 % carbon dioxide to the tested stages of various insect species at grain temperature of 14 ± 1°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	80.0	100	0.0	d
	Egg	54.5	29.4	68.8	-17.9	d
	Larva	88.4	67.3	82.2	-17.8	d
	Pupa	95.5	87.0	95.5	-4.5	d
R. dominica	Adult	95.0	10.0	100	0.0	d
	Egg	63.6	59.3	91.9	-8.1	d
	Larva	78.0	67.0	87.9	-12.1	d
	Pupa	68.1	47.1	86.6	-13.4	d
T. castaneum	Adult	100	5.5	100	0.0	d
	Egg	68.3	48.3	88.3	-11.7	d
	Larva	57.8	20.0	100	28.5	s
	Pupa	57.8	10.0	100	47.5	s
T. granarium larvae	Active	48.9	4.4	100	87.6	s
	Diapause	32.2	4.4	98.9	170.2	s

d = additive effect

s = synergistic effect

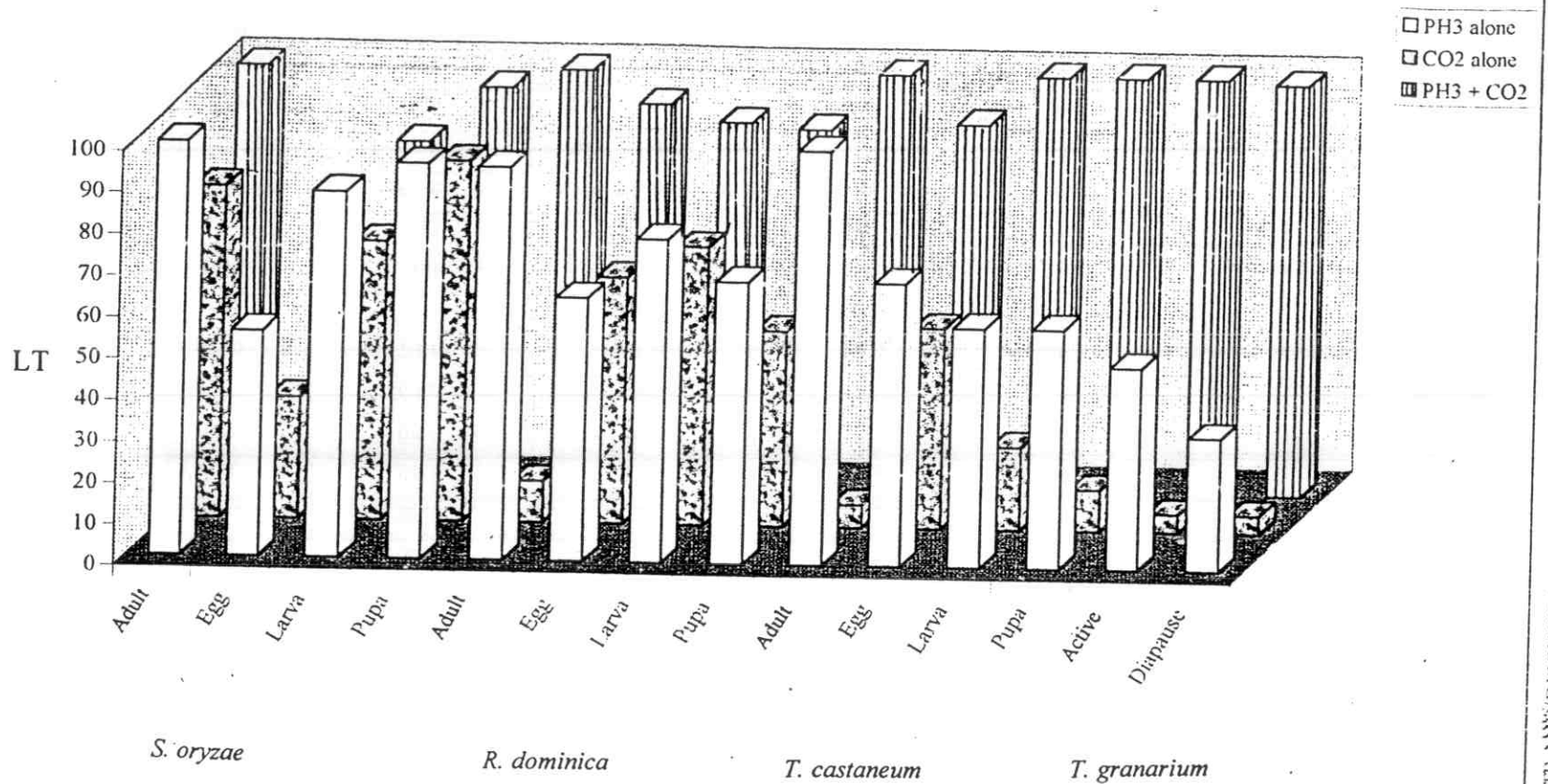


Fig (16): Joint action of 100 ppm PH_3 and 60% CO_2 at 14°C after 2 days.

resulting from the combination of the two gases were higher than those obtained from each gas alone. Co-toxicity values of the mixture indicate additive effects for the different stages of both *S. oryzae* and *R. dominica*. While in case of *T. castaneum*, additive effects were obtained only for the adult and egg stages, while synergistic effect was shown for the larval and pupal stages.

Also, synergistic effect was noticed with both active and diapause larvae of *T. granarium*.

4.3. Efficacy and combined action of 100 ppm phosphine with 60 ±5% CO_2 at grain temperature of 18 ± 2°C.

The results of the efficacy and combined action of 100 ppm phosphine with 60 ± 5% CO_2 to the tested stages of various insect species at grain temperature of 18 ± 2°C and 55 ± 5% R.H. after one day exposure period are shown in Table (14) & Fig (17).

Co-toxicity values resulted from the mixture of phosphine plus carbon dioxide show additive effects for the different stages of *S. oryzae*, *R. dominica* and *T. castaneum*, while in case of the active and diapause larvae of *T. granarium* synergistic effect was noticed.

4.4 Efficacy and combined action of 100 ppm phosphine with 60 ± 5% CO_2 at grain temperature of 20 ± 1°C:

Table (15) & Fig (18) shows the results of the efficacy and combined action of 100 ppm phosphine with 60 ± 5% CO_2 to the tested stages of various insect species at grain temperature of 20 ± 1°C and 55 ± 5% R.H. after 5 days exposure periods.

Table (14): Efficacy and combined action of 100 ppm phosphine with 60 ± 5 % carbon dioxide to the tested stages of various insect species at grain temperature of 18 ± 2°C and 55 ± 5 % R. H. after 1day 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	78.3	56.7	95.0	-5.0	d
	Egg	33.7	14.9	52.0	7.0	d
	Larva	76.3	35.3	89.0	-11.0	d
	Pupa	67.9	15.2	74.2	-10.7	d
R. dominica	Adult	78.9	25.0	92.2	-7.8	d
	Egg	92.6	87.6	96.7	-3.3	d
	Larva	95.3	90.6	93.8	-6.2	d
	Pupa	89.3	81.4	98.7	-1.3	d
T. castaneum	Adult	100	18.9	100	0.0	d
	Egg	61.7	67.5	83.5	-16.5	d
	Larva	100	61.7	100	0.0	d
	Pupa	100	72.2	100	0.0	d
T. granarium larvae	Active	13.3	2.2	33.4	115.5	s
	Diapause	11.1	0.0	15.0	35.1	s

d = additive effect

s = synergistic effect

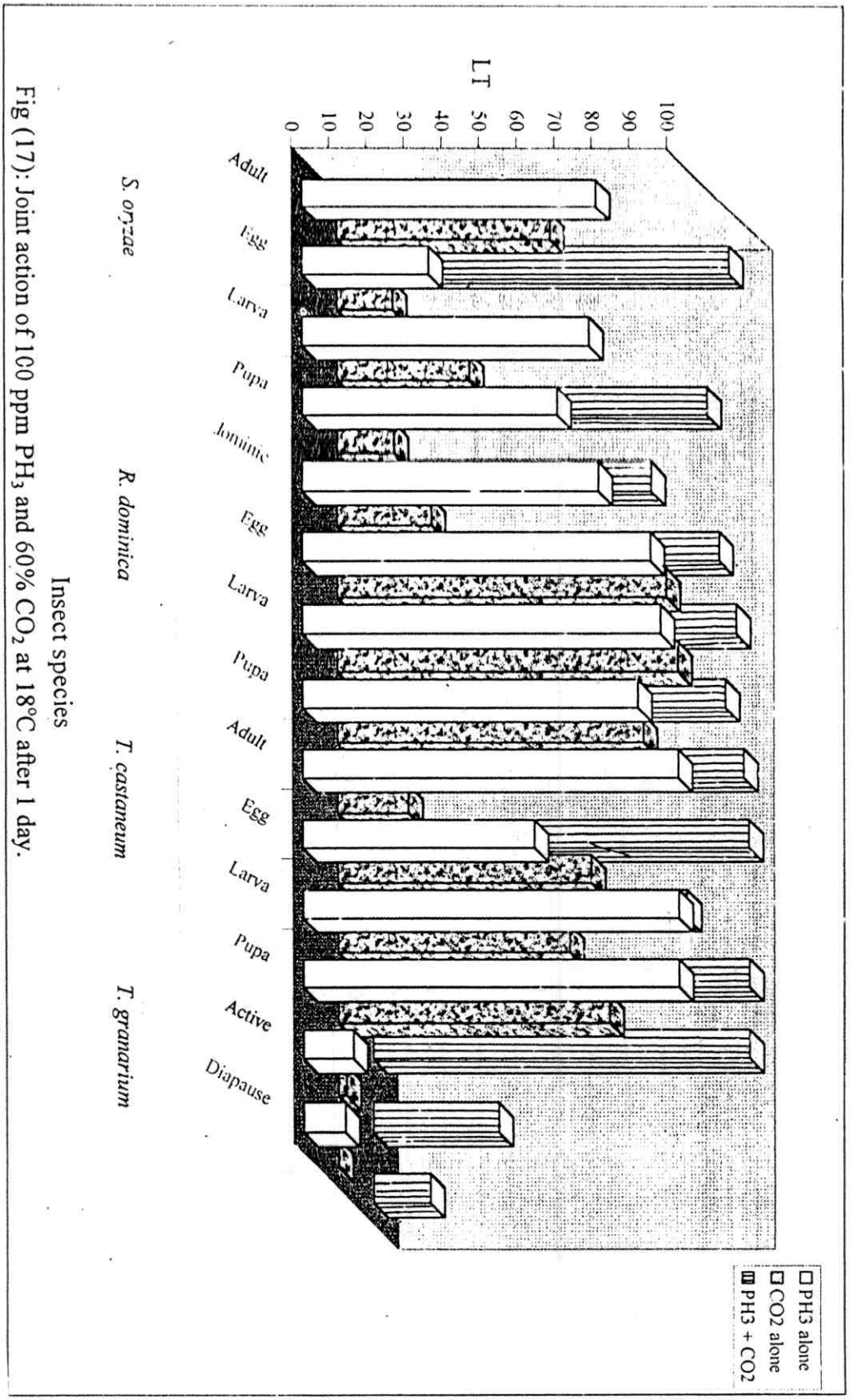


Fig (17): Joint action of 100 ppm PH_3 and 60% CO_2 at 18°C after 1 day.

Table (15): Efficacy and combined action of 100 ppm phosphine with 60 ± 5 % carbon dioxide to the tested stages of various insect species at grain temperature of 20 ± 1°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	96.7	100	0.0	d
	Egg	75.4	50.8	94.3	-5.7	d
	Larva	91.8	77.2	95.0	-5.0	d
	Pupa	57.3	29.6	87.4	0.6	d
R. dominica	Adult	100	100	100	0.0	d
	Egg	79.8	62.0	95.3	-4.7	d
	Larva	92.3	67.9	96.2	-3.8	d
	Pupa	69.8	29.8	97.4	-2.2	d
T. castaneum	Adult	100	100	100	0.0	d
	Egg	60.0	58.3	95.9	-4.1	d
	Larva	100	97.5	100	0.0	d
	Pupa	100	80.0	95.9	-4.1	d
T. granarium larvae	Active	100	48.4	100	0.0	d
	Diapause	100	25.0	100	0.0	d

d = additive effect

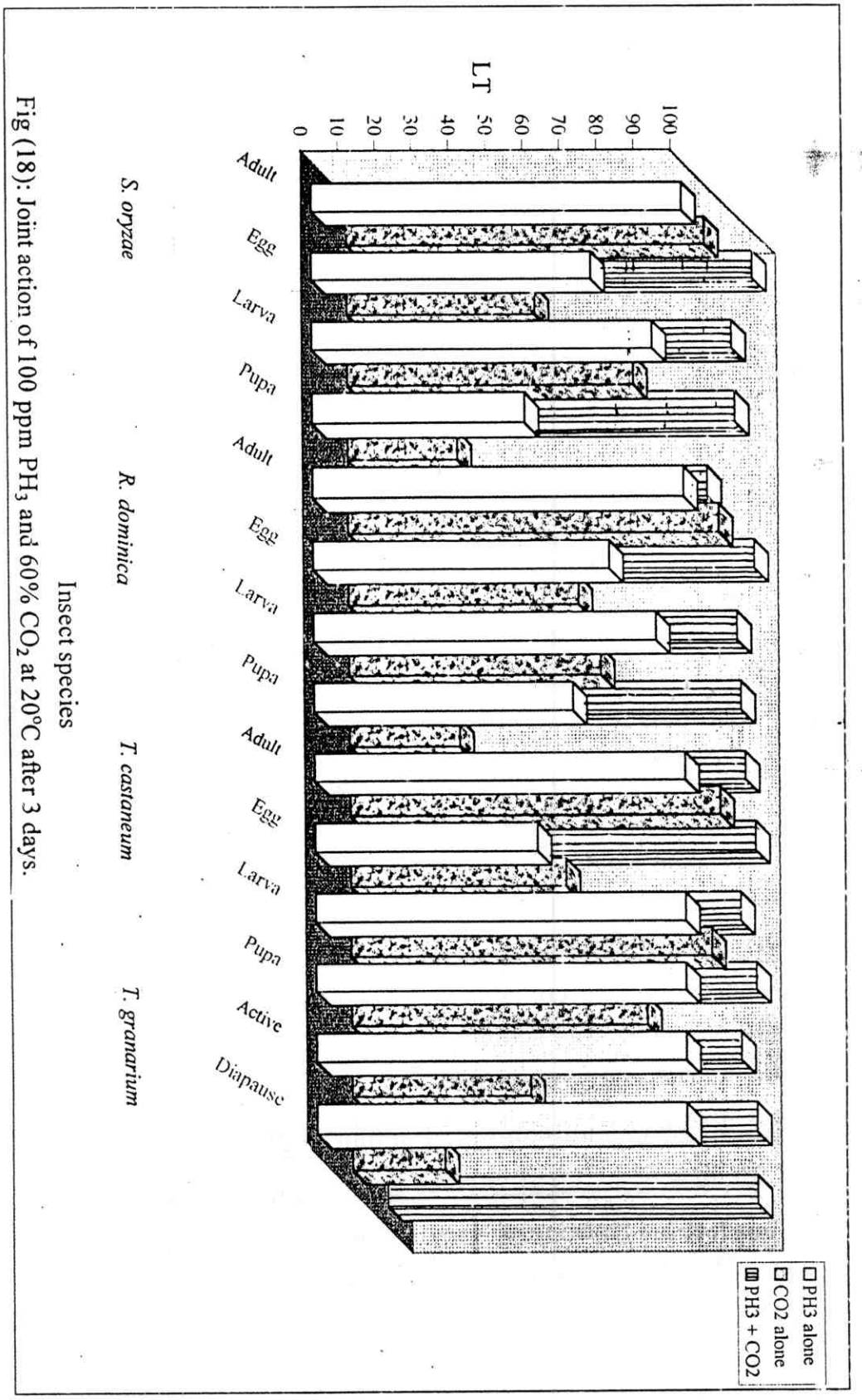


Fig (18): Joint action of 100 ppm PH_3 and 60% CO_2 at 20°C after 3 days.

Data reveal that percentage moralities resulting from phosphine-carbon dioxide-mixture were in general greater than those of each gas alone. Co-toxicity values indicate pronounced additive effects for the mixture with the different stages of all tested insect species.

4.5 Efficacy and combined action of 100 ppm phosphine with 60 ± 5% CO_2 at 24 ± 1°C.

Table (16) & Fig (19) shows the results of the efficacy and combined action of 100 ppm phosphine with 60 ± 5% CO_2 to the tested stages of various insect species at grain temperature of 24 ± 1°C and 55 ± 5% R.H. after 5 days exposure period.

Data indicate that the calculated Co-toxicity values reveal additive effects with the tested stages of all the insect species under study.

4.6 Efficacy and combined action of 100 ppm phosphine with 60 ± 5% CO_2 at 26 ± 2°C.

The results of the efficacy and combined action of 100 ppm phosphine with 60 ± 5% CO_2 to the tested stages of various insect species at grain temperature of 26 ± 2°C and 55 ± 5% R.H. after 7 days exposure period are given in Table (17) & Fig (20). The results showed additive effects with the tested stages of all the insect species under study.

4.7. Efficacy and combined action of 200 ppm phosphine with 80 ± 5% CO_2 at various grain temperatures.

The obtained results are presented in Tables 18, 19, 20, 21 and 22. The results of the efficacy and combined action of 200 ppm phosphine with 80 ± 5% CO_2 to the tested stages of various

Table (16): Efficacy and combined action of 100 ppm phosphine with 60 ± 5 % carbon dioxide to the tested stages of various insect species at grain temperature of 24 ± 1°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	97.9	48.9	98.4	-1.6	d
	Larva	95.9	90.5	99.3	-0.7	d
	Pupa	99.4	77.1	97.2	-2.8	d
R. dominica	Adult	100	100	100	0.0	d
	Egg	80.3	70.9	90.2	-9.8	d
	Larva	85.2	70.4	97.6	-2.4	d
	Pupa	87.8	69.5	89.6	-10.4	d
T. castaneum	Adult	100	100	100	0.0	d
	Egg	100	100	100	0.0	d
	Larva	100	100	100	0.0	d
	Pupa	100	61.7	100	0.0	d
T. granarium larvae	Active	100	50.0	100	0.0	d
	Diapause	100	27.8	100	0.0	d

d = additive effect

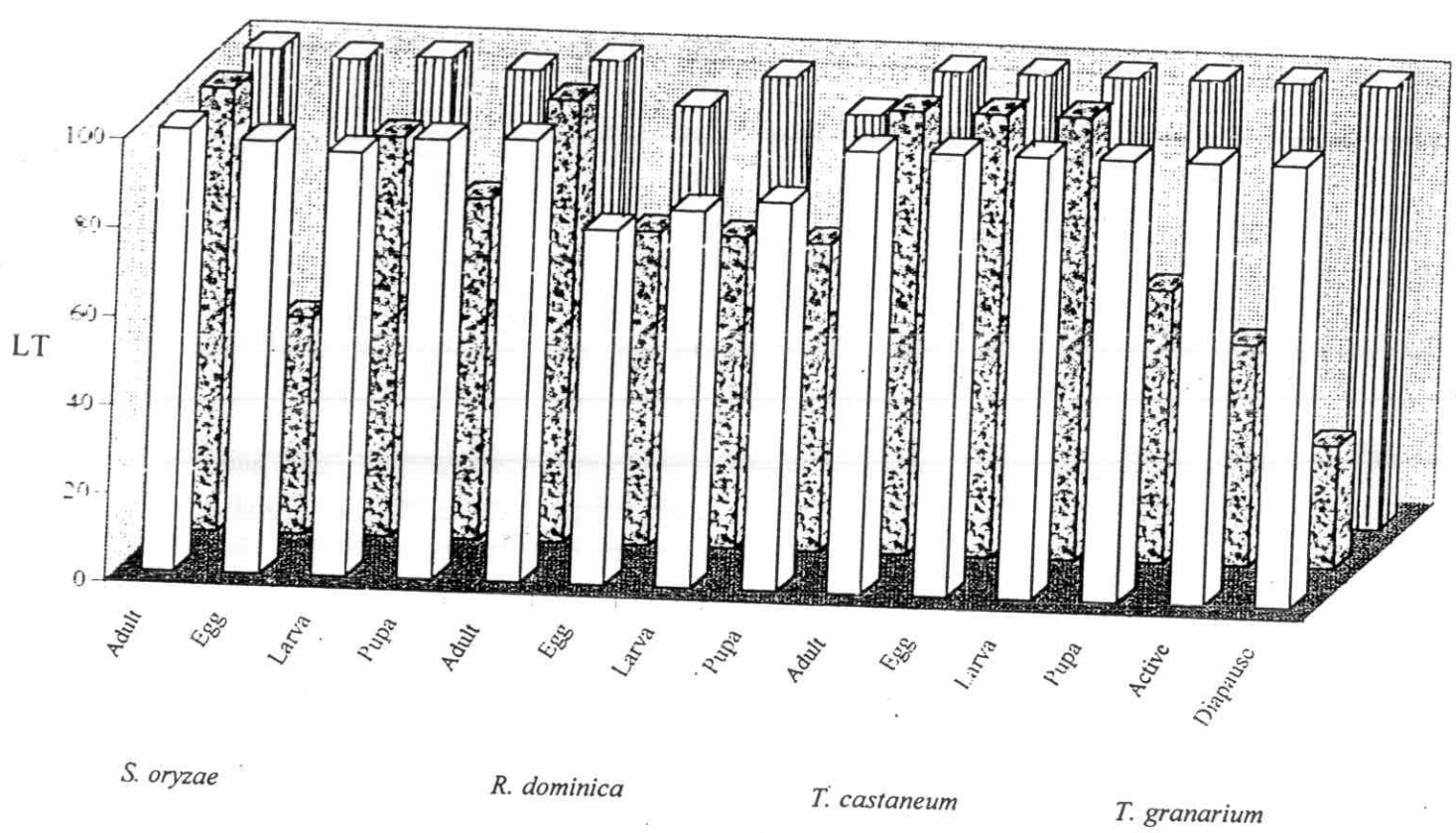


Fig (19): Joint action of 100 ppm PH_3 and 60% CO_2 at 24°C after 5 days.

Table (17): Efficacy and combined action of 100 ppm phosphine with 60 ± 5 % carbon dioxide to the tested stages of various insect species at grain temperature of 26 ± 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	100	89.5	100	0.0	d
	Larva	99.7	89.3	100	0.0	d
	Pupa	92.5	25.6	94.4	-5.6	d
R. dominica	Adult	100	100	100	0.0	d
	Egg	91.6	68.3	95.4	-4.6	d
	Larva	93.7	88.3	95.9	-4.1	d
	Pupa	73.9	40.2	88.9	-11.1	d
T. castaneum	Adult	100	100	100	0.0	d
	Egg	100	93.3	100	0.0	d
	Larva	100	100	100	0.0	d
	Pupa	100	67.5	100	0.0	d
T. granarium larvae	Active	100	77.8	100	0.0	d
	Diapause	100	42.2	100	0.0	d

d = additive effect

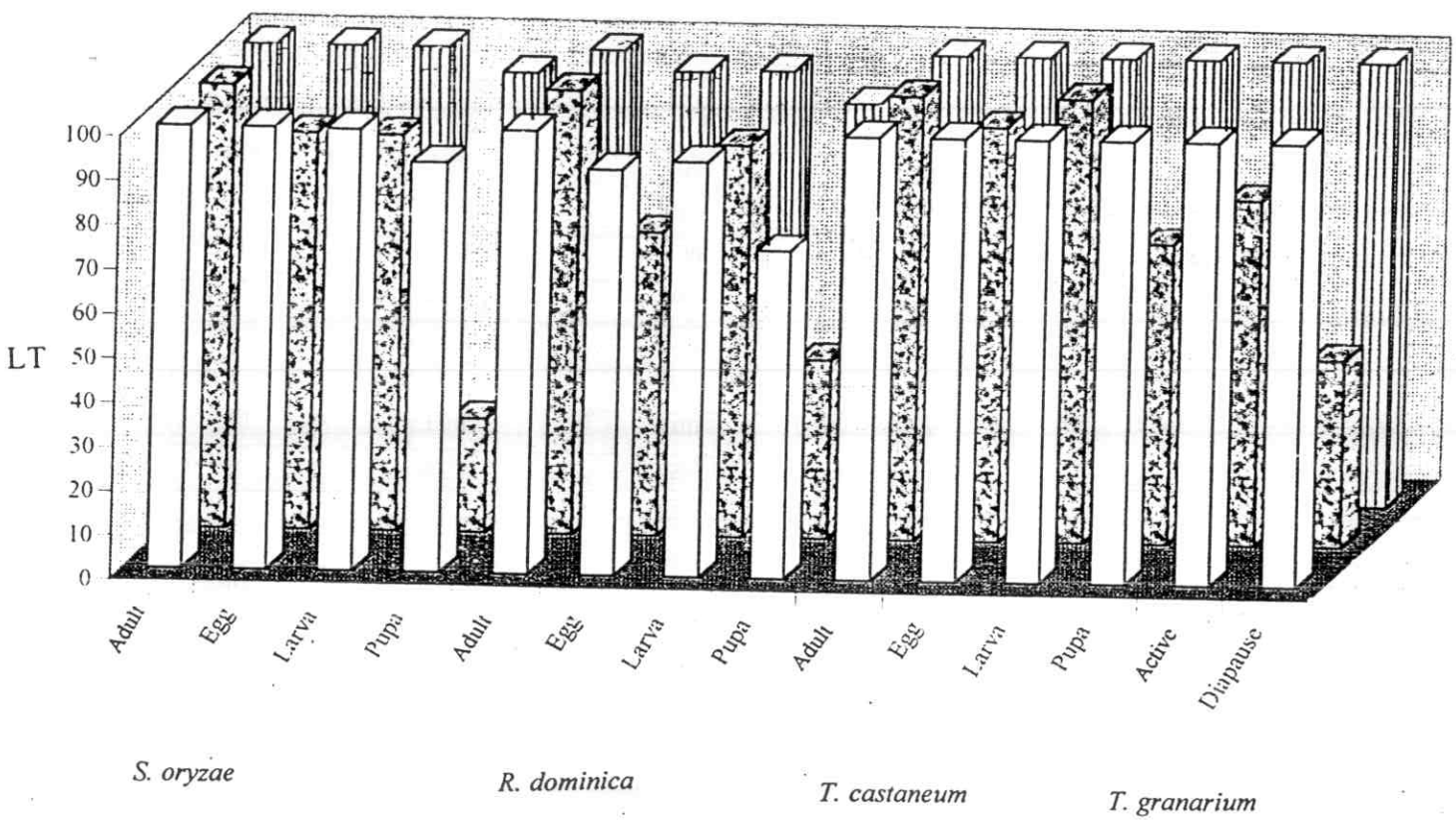


Fig (20): Joint action of 100 ppm PH_3 and 60% CO_2 at 26°C after 7 days.

insect species at grain temperature of 32 ± 2°C and 55 ± 5%. R.H. after one day exposure period are listed in Table (18) & Fig (21). Percentage mortalities resulting from the mixture of phosphine and carbon dioxide were mostly higher than each gas alone.

Co-toxicity values showed additive effects with the different stages of both ***S. oryzae*** and ***R. dominica***, while in case of ***T. castaneum*** additive effect was observed with the adult and pupa, but with the eggs and larvae a synergistic action was shown. Meanwhile, a synergistic effect was also noticed with the active larvae of ***T. granarium***, but a negative effect was achieved in case of the diapause larvae.

The results of the efficacy and combined action of 200 ppm phosphine with 80 ± 5% CO_2 at grain temperature of 32 ± 2°C after 7 days exposure period are presented in Table (19) & Fig (22).

Co-toxicity values of the mixture reveal additive effects with all tested stages of various insect species under study. At the same time, similar result was recorded for this mixture at 28 ± 2°C after 3 days exposure period Table (20) & Fig (23).

The results of the efficacy of 200 ppm phosphine with 80 ± 5% CO_2 to the tested stages of various insect species at grain temperature of 21 ± 1°C and 55 ± 5% R.H. after 2 days exposure period are shown in Table (21) & Fig (24). The results indicate additive effects for the mixture of phosphine plus carbon dioxide with the various stages of ***S. oryzae***, ***R. dominica*** and ***T. castaneum***, while in case of the active and diapause larvae of ***T. granarium*** an antagonistic effect was shown.

Table (18): Efficacy and combined action of 200 ppm phosphine with 80 ± 5 % carbon dioxide to the tested stages of various insect species at grain temperature of 32 ± 2°C and 55 ± 5 % R. H. after 1 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	93.3	100	0.0	d
	Egg	85.2	75.2	100	0.0	d
	Larva	100	100	100	0.0	d
	Pupa	83.4	77.8	100	0.0	d
R. dominica	Adult	78.9	65.0	91.1	-8.9	d
	Egg	45.8	31.0	74.2	-3.7	d
	Larva	95.6	85.0	99.3	-0.7	d
	Pupa	64.6	55.1	98.8	-1.2	d
T. castaneum	Adult	70.0	60.0	97.8	-2.2	d
	Egg	0.0	8.3	41.7	402.4	s
	Larva	24.5	18.4	81.7	90.4	s
	Pupa	73.3	65.6	81.1	-18.9	d
T. granarium larvae	Active	13.3	12.2	68.4	168.2	s
	Diapause	11.1	8.9	15.5	-22.5	a

a = antagonistic effect
d = additive effect
s = synergistic effect

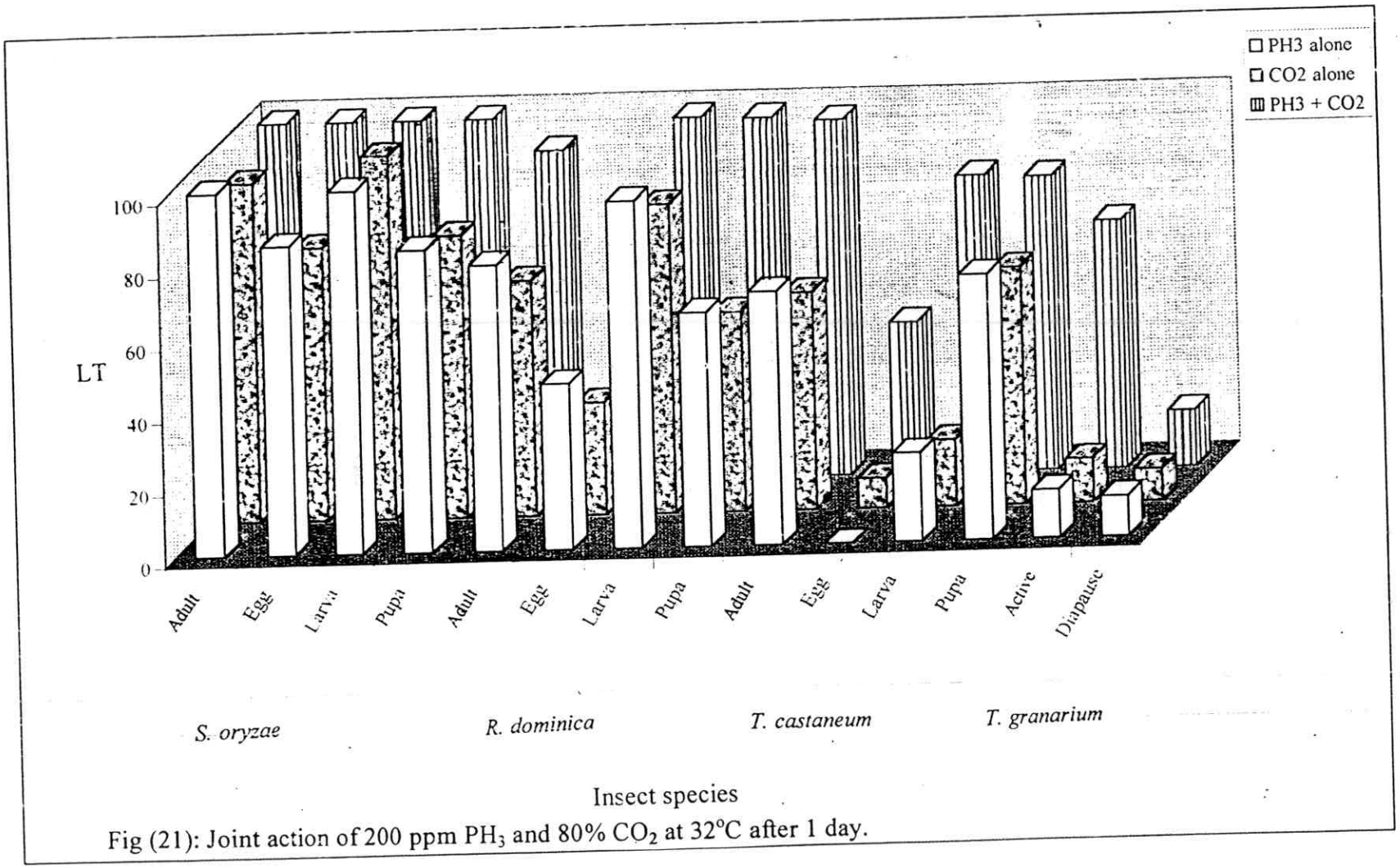


Fig (21): Joint action of 200 ppm PH_3 and 80% CO_2 at 32°C after 1 day.

Table (19): Efficacy and combined action of 200 ppm phosphine with 80 ± 5 % carbon dioxide to the tested stages of various insect species at grain temperature of 32 ± 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	100	100	100	0.0	d
	Larva	100	100	100	0.0	d
	Pupa	100	88.9	100	0.0	d
R. dominica	Adult	100	95.6	100	0.0	d
	Egg	97.0	98.0	94.0	-6.0	d
	Larva	96.6	98.1	97.5	-2.5	d
	Pupa	98.1	98.4	96.5	-3.5	d
T. castaneum	Adult	100	98.9	100	0.0	d
	Egg	91.7	93.3	100	0.0	d
	Larva	100	100	100	0.0	d
	Pupa	100	98.9	100	0.0	d
T. granarium larvae	Active	100	67.8	100	0.0	d
	Diapause	100	35.5	100	0.0	d

d = additive effect

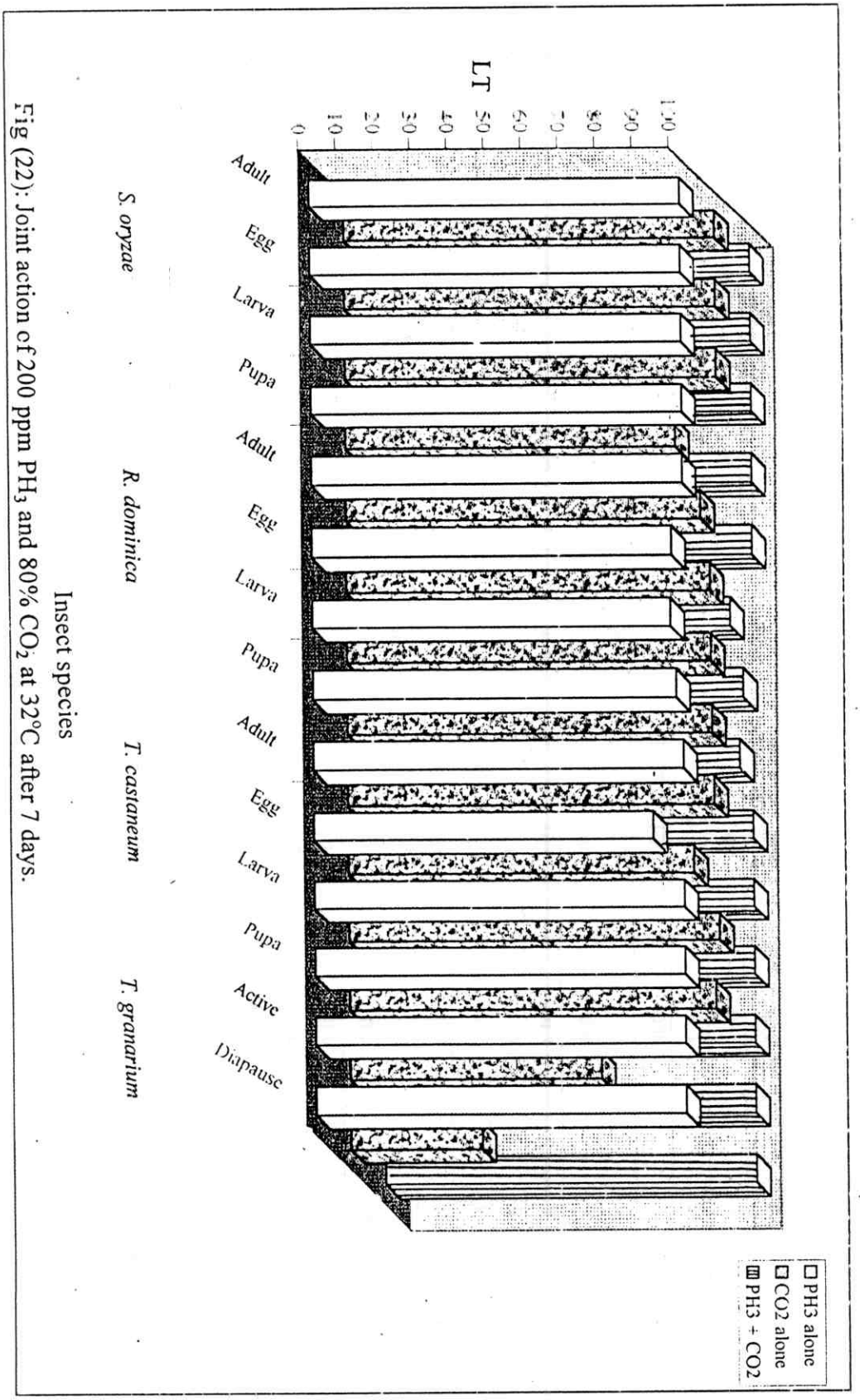


Fig (22): Joint action of 200 ppm PH_3 and 80% CO_2 at 32°C after 7 days.

Table (20): Efficacy and combined action of 200 ppm phosphine with 80 ± 3 % carbon dioxide to the tested stages of various insect species 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	100	100	0.0	d
	Larva	100	86.7	100	0.0	d
	Pupa	97.9	96.7	95.8	-4.2	d
R. dominica	Adult	100	100	100	0.0	d
	Egg	98.8	89.1	99.4	-0.6	d
	Larva	100	99.1	100	0.0	d
	Pupa	97.5	87.8	99.6	-0.4	d
T. castaneum	Adult	100	100	100	0.0	d
	Egg	98.3	96.7	98.3	-1.7	d
	Larva	100	97.5	100	0.0	d
	Pupa	95.6	94.4	96.7	-3.3	d
T. granarium larvae	Active	100	48.4	100	0.0	d
	Diapause	100	27.8	100	0.0	d

d = additive effect

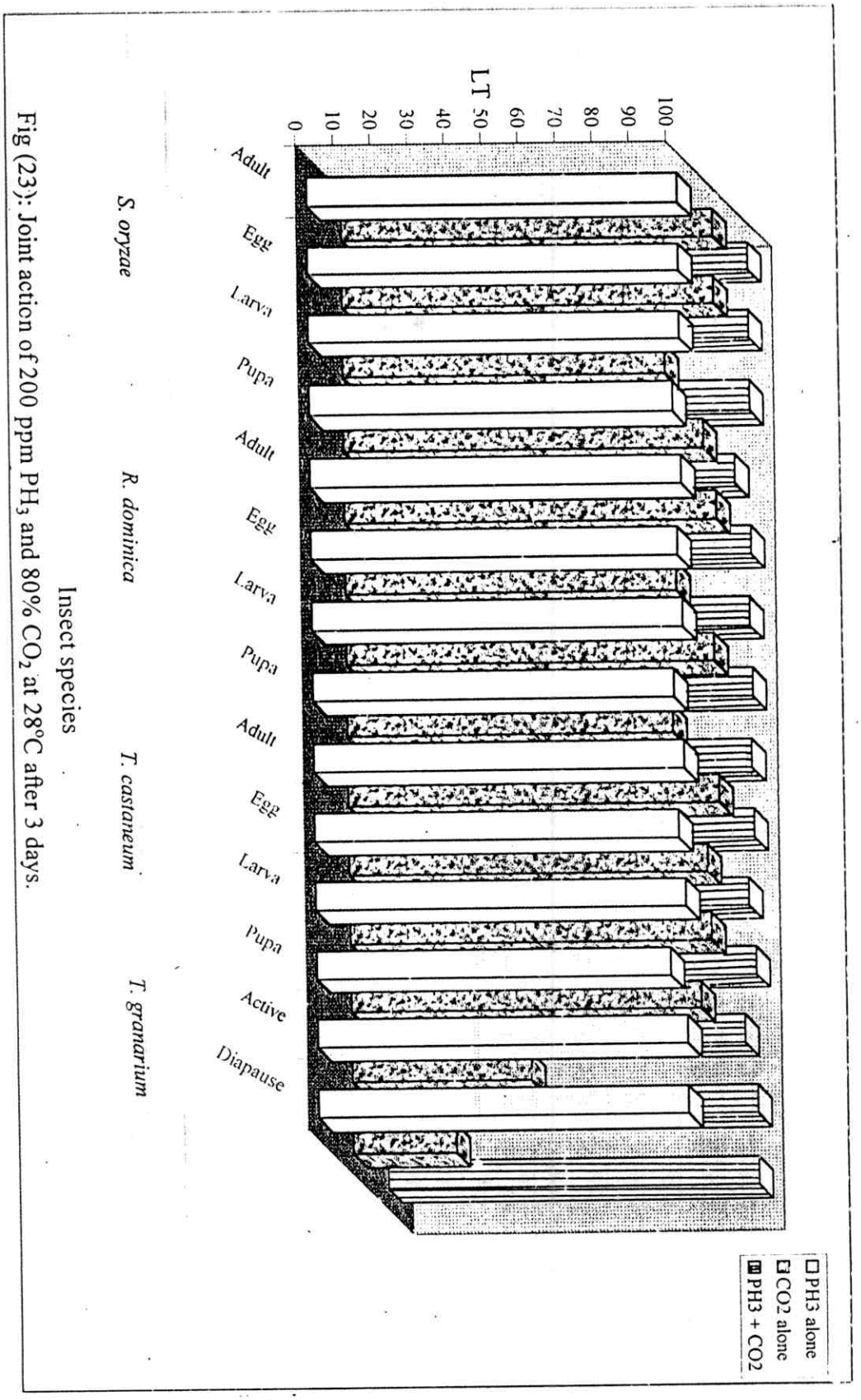


Fig (23): Joint action of 200 ppm PH_3 and 80% CO_2 at 28°C after 3 days.

Table (21): Efficacy and combined action of 200 ppm phosphine with 80 ± 5 % carbon dioxide to the tested stages of various insect species at grain temperature of 21 ± 1°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	97.8	100	0.0	d
	Egg	100	95.4	100	0.0	d
	Larva	100	93.7	100	0.0	d
	Pupa	100	100	100	0.0	d
R. dominica	Adult	90.0	90.0	95.6	-4.4	d
	Egg	87.0	71.7	98.8	-1.2	d
	Larva	77.4	68.6	100	0.0	d
	Pupa	90.8	83.8	100	0.0	d
T. castaneum	Adult	100	85.0	100	0.0	d
	Egg	95.0	70.0	96.7	-3.3	d
	Larva	100	77.9	100	0.0	d
	Pupa	97.8	83.9	98.4	-1.6	d
T. granarium larvae	Active	56.7	76.7	66.7	-33.3	a
	Diapause	54.4	57.8	55.6	-44.4	a

a = antagonistic effect

d = additive effect

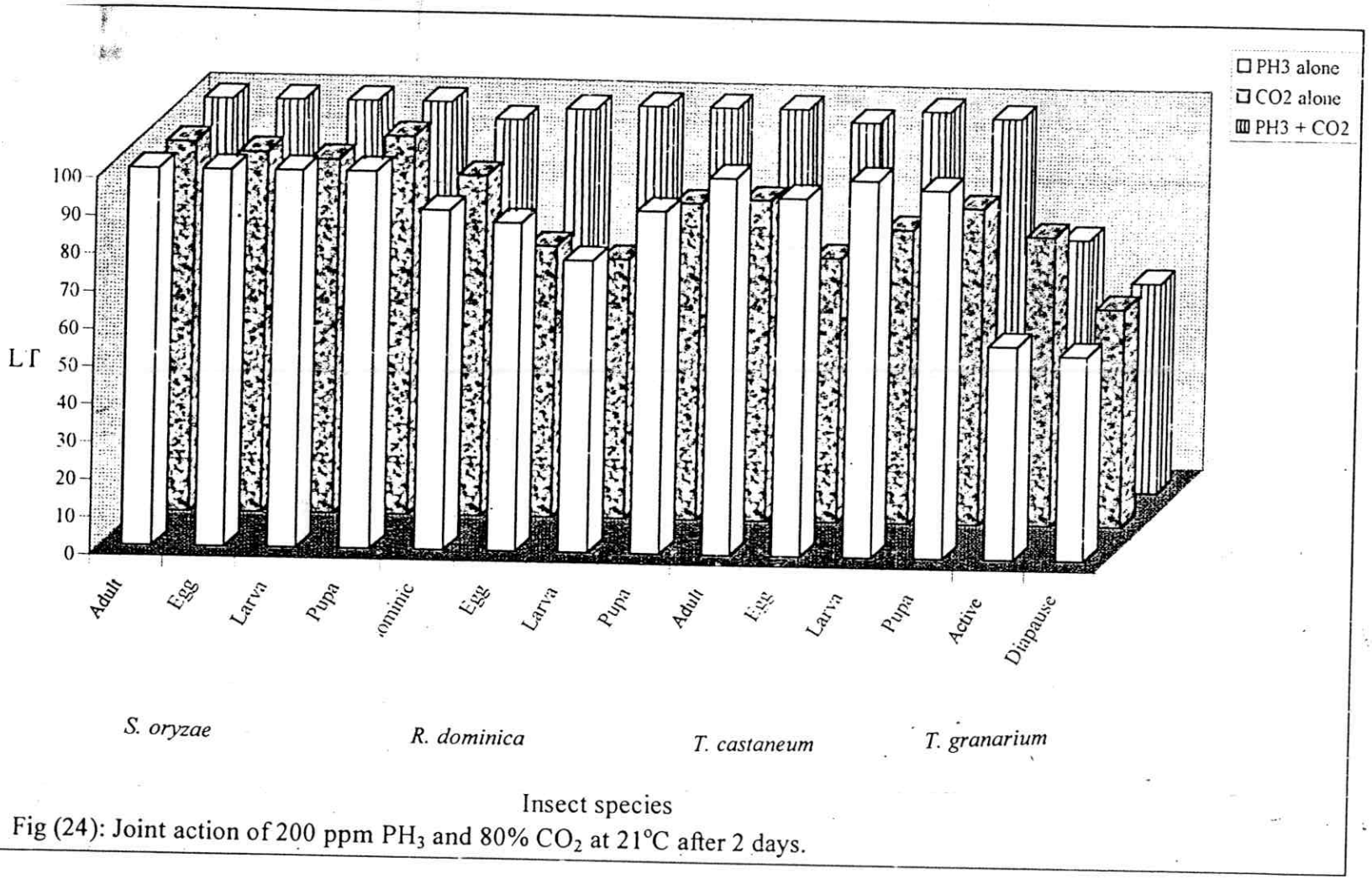


Fig (24): Joint action of 200 ppm PH_3 and 80% CO_2 at 21°C after 2 days.

Table (22) & Fig (25) shows the results of the efficacy of 200 ppm phosphine with 80 ± 5% CO_2 to the tested stages of various insect species at grain temperature of 16 ± 1°C and 55 ± 5% R.H. after 5 days exposure period. These results indicated additive effects for the mixture with all the tested stages of the insects under study.

The obtain 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 and 1992a, b & c.**

Table (22): Efficacy and combined action of 200 ppm phosphine with 80 ± 5 % carbon dioxide to the tested stages of various insect species at grain temperature of 16 ± 1°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	79.4	73.5	90.8	-9.2	d
	Larva	89.8	90.6	99.6	-0.4	d
	Pupa	85.0	50.1	88.4	-11.6	d
R. dominica	Adult	100	100	100	0.0	d
	Egg	60.1	38.9	79.2	-20.0	d
	Larva	68.7	48.6	80.3	-19.7	d
	Pupa	48.0	55.6	81.3	-18.7	d
T. castaneum	Adult	100	100	100	0.0	d
	Egg	100	100	100	0.0	d
	Larva	100	100	100	0.0	d
	Pupa	100	73.3	100	0.0	d
T. granarium larvae	Active	100	43.3	100	0.0	d
	Diapause	98.9	43.3	98.9	-1.1	d

d = additive effect

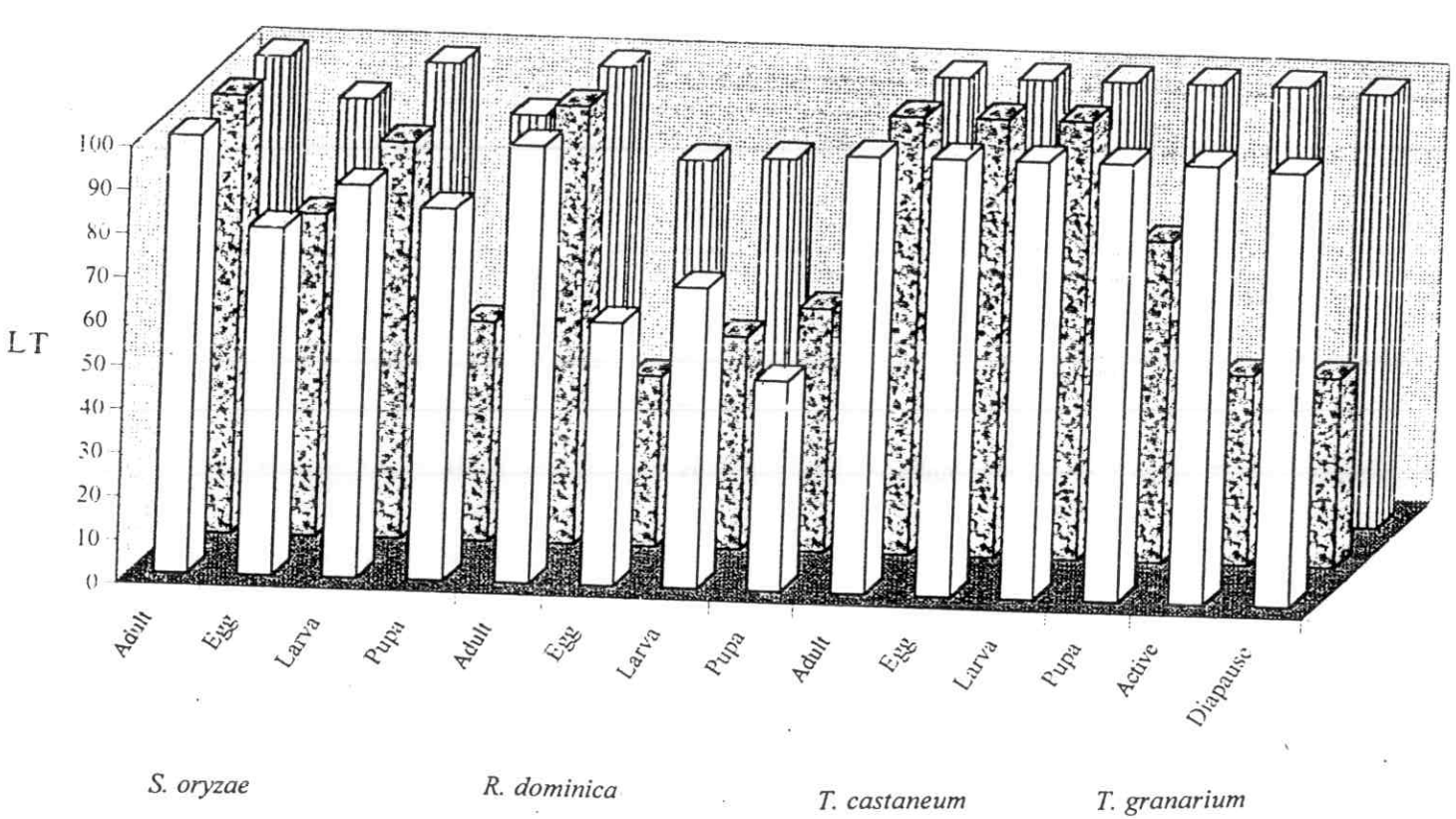


Fig (25): Joint action of 200 ppm PH_3 and 80% CO_2 at 16°C after 5 days.