MODIFIED ATMOSPHERES FOR POSTHARVEST INSECT CONTROL IN TREE NUTS AND DRIED FRUITS

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Raisins are prone to attack from a wide range of insects. Some insects attack ripe grapes before and after they are picked and laid on trays to dry. Examples of insects that attack the grapes are Drosophila spp. and Nitidulid spp. As the grapes dry and become raisins, larvae of the raisin moth, Cadra figulilella (Gregson), attack them. After drying, the raisins are then transported to the raisin processing plants where they are stored as "field run" raisins, that is, raisins attached to their stems. Before the raisins go into storage, they are screened to remove sand, dirt and insects. In storage, the more common stored product insects such as Indianmeal moth, Plodia interpunctella (Hübner); sawtoothed grain beetle, Oryzaephilus surinamensis (L.); red flour beetle, Tribolium castaneum (Herbst); and merchant grain beetle, O. mercator (Fauvel), initiate their infestations. Field-run raisins are generally stored in 4-foot square by 2-foot deep plywood bins that are placed in concrete storage rooms or temporary storages, where they may be held for one year or more. During this time, the raisins must be protected from insect damage.

Once stored, raisins are fumigated with methyl bromide or phosphine and are refumigated at approximately 1 month intervals during the warm season. The fumigations take place in concrete storage rooms or in paper covered temporary storages. The temporary storages are considered to be more airtight than are the concrete storages and were the subject of a recent modified atmosphere test. The temporary storages (stacks) are constructed by stacking the raisin bins 10 wide, 9 high and variable lengths. A wood framework is nailed to the outside of the bins and two layers of Fibreen(R) (plastic coated, tar laminated, Kraft paper) are placed over the framework, and attached by nailed wooden slats. The bottom edge of the Fibreen cover is sealed to the concrete with oiled dirt. Two sizes of these storages were used in our tests; one was 20 bins long, contained 1600 bins and enclosed 1869 m^3, and the second was 35 bins long, contained 2800 bins and enclosed 3308 m^3.

The low-oxygen atmosphere used in the tests was generated with a model XH-1000-NM-HE inert gas generator (Gas Atmospheres Inc., Port Washington, WI) rated at 283 m^3/h. The generated low oxygen atmosphere (GLOA) contained ca. $\leq$ 0.5% oxygen, 12-14% carbon dioxide, 1% argon and the balance mainly nitrogen. Introduction of GLOA into the stacks was

through a 10 cm diameter pipe inserted through the cover ca. 30 cm above the floor at one end of the stacks. An outlet vent (161 cm^2) was made at the top-center of the opposite end of the stacks. Application of GLOA utilized a single pass system and had two phases. The initial, or purge, phase consisted of allowing the atmosphere to flow at a high rate such that it rapidly (24-48 hour) displaced the existing storage atmosphere. After the desired oxygen level (0.5% oxygen) was attained, the maintenance phase was started, and consisted of closing the outlet vent and simultaneously reducing the input rate. The maintenance flow rate (ca. 8.5-17 m^3/h) maintained a positive internal pressure and prevented atmospheric oxygen from reentering the storage. Maintenance was continued for the duration required to kill the insects. Research with the 283 m^3/hr generator showed purge-phase times of 24 and 48 hr respectively, for 1869 m^3 and 3308 m^3 temporary raisin storages. Reducing the flow rate to 141 m^3/hr in the smaller storage doubled the purge time (Fig. 1). Selected insects were placed in both storages to determine insect kill-times; the results are given in Tables 1 and 2 at 27°C and 16°C, respectively. Drosophila melanogaster required the longest exposure (120 h) for complete control at 27°C. All other species were controlled within 60 h. The lower temperature (16°C) extended the kill time to 5 days except for D. melanogaster which required over 14 days. It should be noted that under normally dry storage conditions, D. melanogaster cannot survive and reinfest the stored raisins.

An economic study was made (Gardner et al. 1982) to determine the cost of utilizing a generated low-oxygen atmosphere for insect control in raisins, and to compare it to the estimated cost of using methyl bromide, phosphine or nitrogen under similar conditions (Table 3). These costs reflect the cost of building the Fibreen-covered storage and applying the method of fumigation each month for an average six month storage period. The cost of utilizing GLOA was found to be competitive with current fumigation costs, while the use of on-site production or trucking of liquid nitrogen was not.

Generated low-oxygen atmosphere testing has been started in bulk stored almonds. Tests of ca. 3000 ft^3 of storage has been conducted under plastic covers and in a steel silo. Under these conditions, the application of the atmosphere and insect mortality were found to be satisfactory. Large scale testing has recently been completed in concrete silos 30 m by 7.3 m diameter that contained 450 metric tons of inshell almonds. Navel orangeworm, Amyelois transitella (Walker), is the major pest of almonds received from the field. Insect mortality data for navel orangeworm pupae and Indianmeal moth pupae are shown in Table 4. Testing in a concrete rectangular-shaped building of tiltup construction is currently underway.

The effect of generated low-oxygen atmosphere on raisin and almond flavor quality was determined by exposing the commodities continuously to the atmosphere for various time periods of up to 1 year (Guadagni et al. 1978a,b). No adverse flavor was detected by the taste panel, and in the case of shelled almonds stored at 27°C, the flavor was maintained by the GLOA whereas it was not maintained when nuts were stored under normal atmosphere. Short exposures (3 days) of carbon dioxide on almond and walnut flavor was determined to have no adverse effects (unpublished).

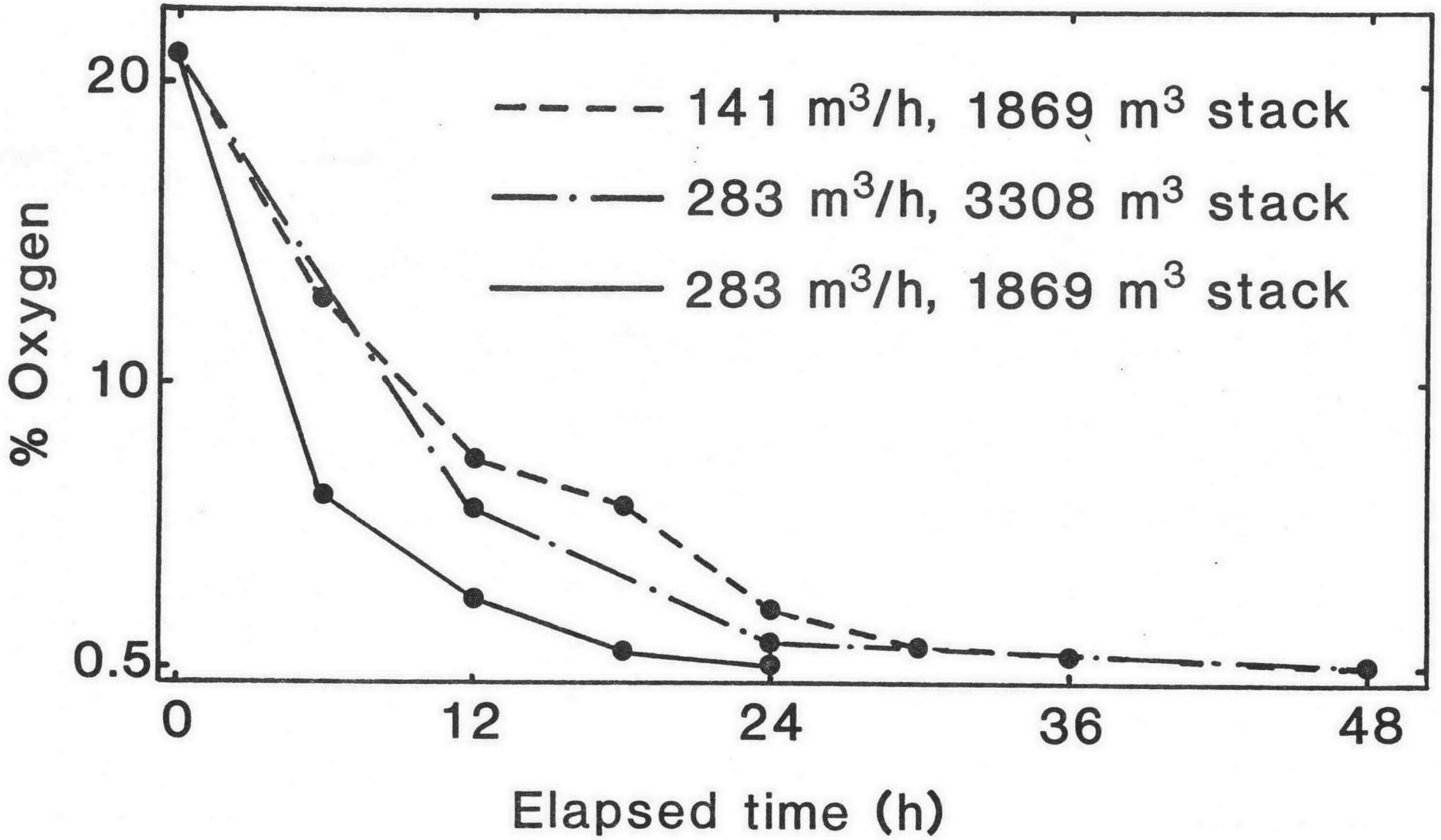

Figure 1. Oxygen content (%) of storage atmosphere during purge phase of two raisin storages.

Table 1.--Percent mortality of insects exposed to a generated low-oxygen atmosphere during treatment of a 3308 m^3 Fibreen-covered, raisin stack at an average temperature of 27°C.

Insect species	Control	Percent mortality after indicated treatment: Exposure Time (h)[a/]						
		48	60	72	84	96	108	120
Cadra figulilella	12	-[b/]	-	100	-	100	-	100
Plodia interpunctella	2	100	100	100	100	100	100	100
Drosophila melanogaster	24	27	40	79	93	96	99	100
Carpophilus hemipterus[c/]	0	33	100	100	100	100	100	100
Oryzaephilus surinamensis								
adults	1	100	100	100	100	100	100	100
larvae	6	100	100	100	100	100	100	100
Tribolium castaneum								
adults	1	100	100	100	100	100	100	100
larvae	2	61	100	100	100	100	100	100

a/ Time measured from initiation of the purge; purge was completed at first sampling (48 h).

b/ No insects sampled.

c/ Mortality of C. hemipterus is based on the number of cultures without survivors, 3 cultures per exposure period.

Table 2.--Percent mortality of insects exposed to a generated low-oxygen atmosphere during treatment of a 1869 m^3 Fibreen-covered, raisin stack at an average temperature of 16°C.

Insect species	Percent mortality[a/] after indicated treatment									
	Control	Exposure time (days)[b/]								
		2	3	4	5	6	7	8	10	12	14
Cadra figulilella	2	38	86	99	100	100	100	100	100	100	100
Plodia interpunctella	5	55	100	100	100	100	100	100	-	-	-
Drosophila melanogaster	12	33	44	37	51	56	59	83	81	95	99
Carpophilus hemipterus[c/]	0	0	0	0	100	100	100	100	100	100	100

a/ Average of three replicates per species and exposure period.

b/ Time measured from initiation of the purge; purge was completed at day 1.

c/ Mortality of C. hemipterus is based on the number of cultures without survivors, 3 cultures per exposure period.

Table 3.--Cost estimates per ton for various methods of disinfesting stored, Fibreen-covered, raisins for an average period of six months.

Method	Cost per ton of raisins treated *
Methyl bromide	$ 7.61
Low-oxygen atmosphere	
90% heat recovery	8.77
80% heat recovery	8.88
0% heat recovery	9.66
Phosphine	9.77
Nitrogen	
On site production	15.91
Trucked	20.12

*1981 USA dollars based on Fresno, CA location

Table 4.--Percent mortality of navel orangeworm and Indianmeal moth in a concrete silo treated with a generated low-oxygen atmosphere. The purge phase lasted 8 hours and the first insect samples were removed 12 hours after completion of the purge. The average temperature was 27°C.

	Percent mortality					
	Control	Exposure time after purge				
Insect species		12	24	36	48	60
Amyelois transitella	7	10	15	62	96	100
Plodia interpunctella	1	34	84	100	100	100

Long term exposure effects need further evaluation.

Laboratory studies have been conducted to study the time-mortality effects of various low-oxygen atmospheres on the navel orangeworm (Storey and Soderstrom 1977, Brandl et al. 1983), and to examine the effects of the variables of oxygen concentration, relative humidity, and temperature on the navel orangeworm and Indianmeal moth (unpublished). The tests were conducted with bottled gases that were analyzed with a Fisher model 1200 gas partitioner or with a Taylor Servomex Oxygen Analyzer, OA-250. Gases were humidified with glycerine-water solutions of known densities. Test insects were naked pupae and were placed in 470 cm^3 glass jars or (25 cm^3) plastic vials that allowed the atmosphere to enter at the bottom and exit from the top.

Results of oxygen level, relative humidity and temperature effects are in Figs. 2 and 3. The time required for insect kill is proportional to the oxygen level and temperature for Indianmeal moth and navel orangeworm with Indianmeal moth being easiest to kill. Relative humidity had a greater effect on the mortality of the navel orangeworm than it did on Indianmeal moth. A possible explanation may be that the navel orangeworm is a pest that initiates its infestation mainly in the field on nuts of higher moisture content. Further laboratory studies are currently underway to compare the generated low-oxygen atmosphere to a carbon dioxide enriched atmosphere (60% CO_2) at the two relative humidities and three temperatures.

Almonds are infested in the field by navel orangeworm and the insects enter storage with the nuts. Some bulk storages require several weeks to fill with nuts. During this time the navel orangeworm moves from nut to nut and continues feeding. Research was conducted to determine the effect of a generated low oxygen atmosphere or a carbon dioxide enriched atmosphere on preventing insect feeding (Soderstrom and Brandl 1982). Navel orangeworm and Indianmeal moth larvae were placed on a rearing medium that contained a red dye. These cultures were treated with various levels of oxygen and carbon dioxide. After 20 hours, the larvae were frozen for later examination for ingested dyed food diet. Both low oxygen and high carbon dioxide reduced insect feeding, and navel orangeworm was more susceptible (Table 5). Thus, purging a storage at the start of the nut- filling operation would be beneficial in reducing insect damage to the nuts.

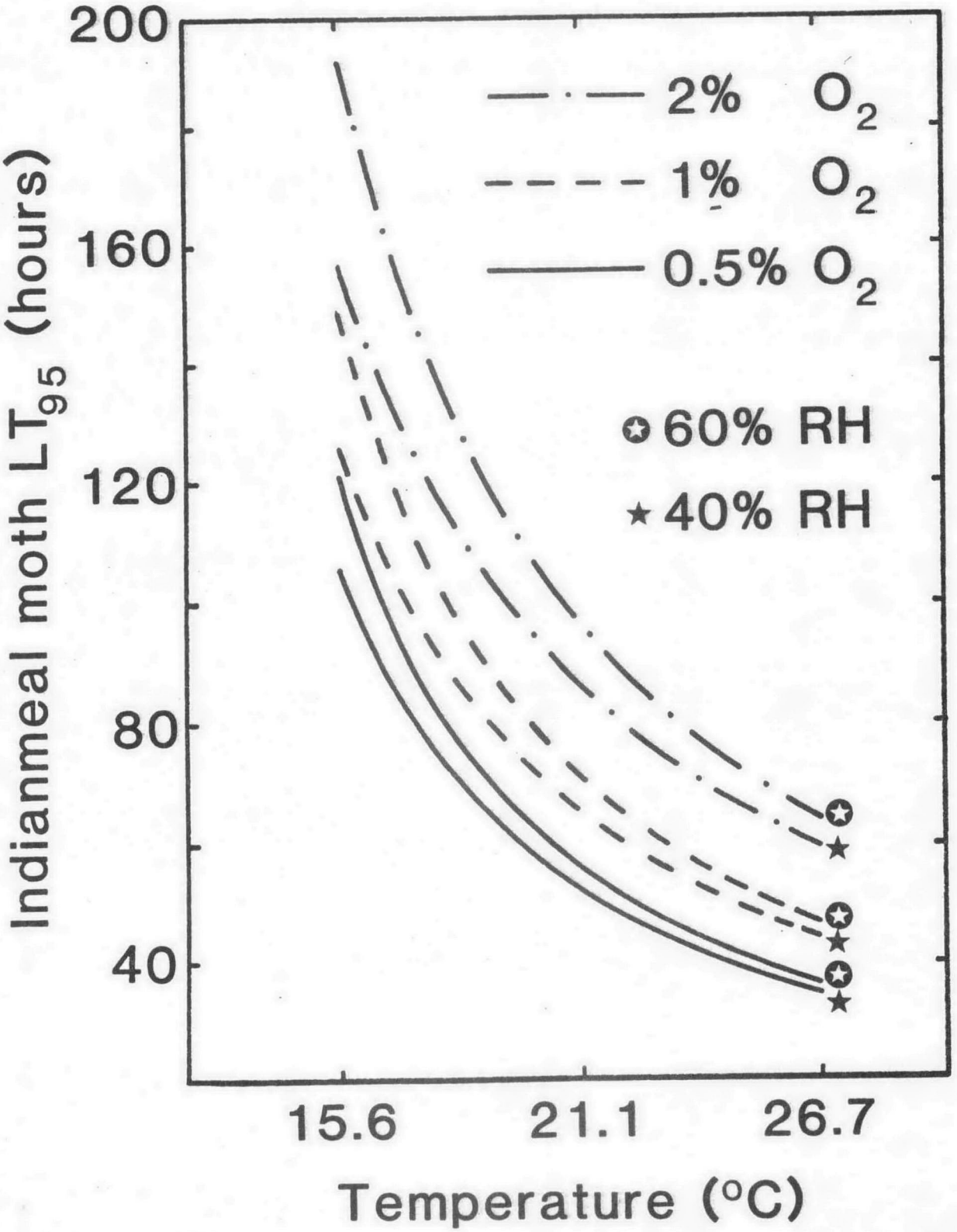

Figure 2. Interaction of temperature, relative humidity, and oxygen on time to kill Indianmeal moth pupae.

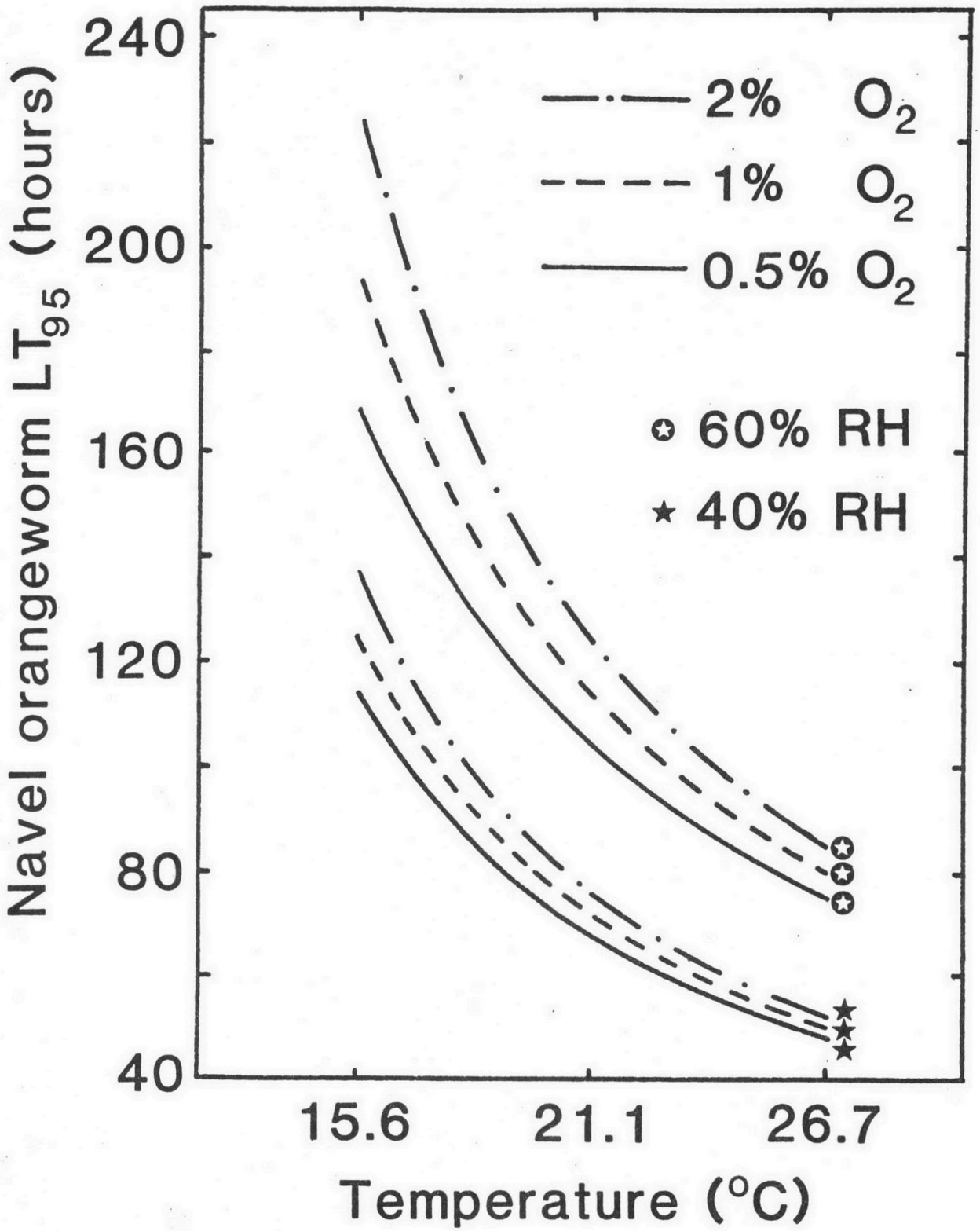

Figure 3. Interaction of temperature, relative humidity, and oxygen on time to kill navel orangeworm pupae.

Table 5.--Percentage of Indianmeal moth and navel orangeworm larvae that fed while exposed to nitrogen- or carbon dioxide-enriched atmospheres[a]

Insect	Normal Atmosphere	Nitrogen treatment ($\% O_2$)[b]			Carbon dioxide treatment ($\% CO_2$)[c]		
		1	2	4	20	30	40
IMM	96 (2.0)	14 (5.9)	58 (12.9)	86 (5.8)	70 (10.6)	43 (12.7)	1 (1.4)
NOW	99 (0.4)	2 (1.0)	97 (2.0)	94 (2.5)	96 (1.8)	5 (3.9)	0

[a]Five replicates, 30 larvae each treatment, IMM 9 to 11 days old, NOW 19 to 21 days old. Values represent averages; values in parenthese represent SE.

[b]Resulting O_2 concentration from addition of N_2 to air.

[c]CO_2 concentration was determined with an O_2 meter calibrated with known concentrations of CO_2.

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