A TWO-STAGE LOW-OXYGEN TREATMENT TO CONTROL NAVEL ORANGEWORM AND INDIANMEAL MOTH IN WALNUTS

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Navel orangeworm (NOW), *Amyelois transitella* (Walker), is the major insect pest of walnuts and most other tree nuts entering storage. Indianmeal moth (IMM), *Plodia interpunctella* (Hübner), is the major pest during storage. Both are controlled by fumigation with methyl bromide or phosphine. During long-term storage, periodic fumigations are applied to control IMM.

An alternative to chemical fumigation is low-oxygen controlled atmospheres (low-O_2). The effectiveness of low-O_2 atmospheres is dependent on several factors: the gaseous composition, temperature, relative humidity (RH), the insect species and life stages present, and most importantly, the duration of treatment. This research develops a two-stage low-O_2 treatment for walnuts. The first stage kills NOW and the second stage keeps the nuts free of subsequent infestation by IMM in long-term storage.

Development of Stage 1. Prior research on NOW identified late larval and early pupal stages (25 d-old, 26.7 °C) as the stages most tolerant to low-O_2 atmospheres (Storey & Soderstrom 1977). The interaction of temperature, RH, and O_2 concentration on mortality of these stages was described by Soderstrom et al., 1986. Time to kill 95% (LT_{95}) was 72.3 h at 26.7 °C, 60% RH, with an atmosphere of 0.5% O_2. Using parameter estimates from that research (unpublished) we projected a $LT_{99.997}$ (probit 9) of 132.7 h (5.5 d).

We validated the estimate by infesting walnuts with 25 d-old NOW and treating them with 0.4% O_2 at 25°C, 60% RH. Steel drums were loaded with 32 kg of Hartley walnuts. Two hundred infested nuts, contained in cheese cloth bags, were buried in the top of the nut mass. After exposure periods of 4, 5, 6, and 7 d, the treated nuts were held 8 w for adults to emerge. Fifty untreated nuts were held for controls. Tests were replicated 3 times. Control emergence averaged 66.5%. Adjusted mean NOW mortality for the treated nuts was 94.8% (4 d), 99.5% (5 d), and 100% (6 d and 7 d), demonstrating an adequate fit to the probit 9 estimation.

Development of Stage 2. Laboratory tests were designed to determine the O_2 concentration needed to prevent IMM from reproducing and infesting the product. IMM eggs 0-24 h-old were sowed on bran diet in 475 ml jars and treated at 25°C, 60% RH for 6 w with atmospheres of 5, 6, 7, or 8% O_2. Controls were treated with air. Six hundred eggs per atmosphere were used for each of 4 replications. After treatment the jars were held until all adults emerged. An

atmosphere of 5% O_2 prevented IMM from developing (Table 1). In other tests, we found that eggs treated for 7 d with 5% O_2 did not hatch.

Final two stage low-O_2 treatment. Final tests were performed in a controlled atmosphere room (3 m square by 2.4 m high) that was sealed to a pressure half life of ≥ 1 minute. A second, similar room for controls was untreated. Standard bins (1.2 m square by 0.6 m high) were loaded with 227 kg of Hartley or Franquette walnuts. Four hundred NOW infested walnuts in cheese cloth bags were buried in the bins and 200 were held as controls. A hollow fiber membrane gas separation system (Permea Inc., St. Louis, MO) was used to produce the low-O_2 atmosphere. The room was purged to 0.4% O_2 in 2 d and held at that level for 6 d. Temperature was maintained at 25°C and RH was ambient. After venting the room, the infested walnuts were removed and held in glass jars for adult NOW to emerge.

Upon completion of the first stage treatment, the room was resealed, purged to 5% O_2, and held at that level for 13 w. Each week for the next 11 w, 5 mated pairs of IMM were introduced into the low-O_2 and control rooms through ports. At 13 w, the low-O_2 room was vented and walnut samples were collected from each of 4 bins. A 100 nut sample per bin was cracked open and examined for insects, and 5 1-kg "bucket" samples per bin were held 8 w for adult IMM to emerge. In addition, a large sample (about 35 kg) was held in a steel drum for 8 w. These nuts were sieved to collect insects.

The control room was sampled as follows. A 100 nut sample per bin was collected at 4 w intervals, cracked open and examined for insects. At the end of the test, 5 1-kg "bucket" samples per bin were held 8 w for adult IMM to emerge. The steel drum sample was not collected due to heavy IMM infestation in the control room. The tests were replicated 3 times.

No NOW survived the first stage treatment, except in the third replication. During this replication, problems developed that resulted in the O_2 concentration rising to 0.7%. Three adults emerged from the 400 infested walnuts and 3 live larvae were found (2 later died). IMM were completely controlled with the second stage 5% O_2 atmosphere. No larvae or adults were found in any of the samples.

Emergence of NOW from controls averaged 80.6% for the three replications and nearly all of the walnuts in which they were contained were infested with the F_1 generation. IMM larvae found in the control nut-crack samples averaged 226 per 400 walnuts by 12 w for the three replications (Table 2). The total number of adults that emerged from the 20 "bucket" samples averaged 1271 for the three replications.

The initial disinfestation of a stored product, such as tree nuts and dried fruits, with controlled atmospheres requires a low-O_2 concentration to be effective against the most tolerant insect life stage present. Generally atmospheres need to be ≤1% O_2 to be effective in a reasonable period of time. This research is novel in the use a relatively high (5%) O_2 atmosphere to suppress subsequent infestations by IMM. In this situation the impact is on the more susceptible egg stage. Maintenance with 5% O_2 will be more economical than with lower O_2 concentrations.

References

Storey & Soderstrom. 1977. J. Econ. Entomol. 70: 95-97.
Soderstrom et al. 1986. J. Econ. Entomol. 79: 1303-1306.

Table 1. Mortality of Indianmeal moth treated with low-O_2 atmospheres for 6 weeks.

Atmosphere	% Mortality (CI)	Adjusted % Mortality
Air	7.9 (5.7 - 11.0)	--
8% O_2	60.1 (51.9 - 69.0)	57.4 (49.0 - 65.1)
7% O_2	95.0 (93.0 - 96.5)	94.6 (92.6 - 96.0)
6% O_2	99.9 (99.7 - 100)	99.9 (99.7 - 100)
5% O_2	100	100

Table 2. Average number per replication of IMM in control samples.

Sample Interval	Nut Crack Samples Larvae/400 nuts	Bucket Samples Adults/20 kg nuts
0 w	0	--
4 w	2	--
8 w	36	--
12 w	226	1271