AERATION OF GRAIN AS A NON-CHEMICAL METHOD FOR THE CONTROL OF INSECTS IN THE GRAIN BULK

S. NAVARRO
Agricultural Research Organization
Stored Products Division
Jaffa, ISRAEL

ABSTRACT: Low temperature ranges that suppress development of stored-grain insects are reviewed. Possibilities of cooling grain builk either by aeration with selected ambient air or refrigerated air are considered. Use of aeration with ambient air in temperate climates and in countries having a cool season is reported. Some examples of the studies carried out under British and Australian climates are discussed.

Data are presented on observations carried out in Israel. A wheat bulk of 1142 tonnes aerated with ambient air resulted in reduction of grain temperature from 32.2°C to 10.5°C. During storage over 22 months the grain remained free from insect development.

Trials conducted with refrigerated air showed that under summer conditions a bin containing 699 tonnes of wheat was cooled from 30-37°C to 18-19°C during 160 hr. The presence of a live insect population in the bin appeared to be responsible for a gradual rise in temperature. In a similar bin cooled from 30-34°C to 16-19°C, insect infestation was lower and the subsequent temperature rise was also less pronounced. Under the reported climatic conditions, the trials indicated that cooling with refrigerated air could be achieved throughout the year and at a higher rate of cooling than by aeration with selected ambient air.

It is shown that sufficient cooling to prevent insect infestation can be obtained and this method seems to be most efficient when the initial insect population is very low. However, possible changes in the biology and composition of the stored products fauna should be envisaged due to the alteration of the microclimate of the grain bulk.

In many countries, aeration has been used successfully by commercial storage operators and has become the accepted practice for preserving grain in storage. Most of the experiments on aeration have been carried out in temperate climates and there is little know-how on the use of aeration systems in other climates. The development of this technique, using ambient or refrigerated air for cooling grain bulks has emphasized the need for more research.

Cooling by aeration may reduce the need for chemical treatments to control insect infestation, in addition to the beneficial effect of aeration in improving the keeping qualities of grain.

The aim of this work was to evaluate the efficacy of aeration in controlling stored product insects in grain bulks, and to consider the biological effects of this control method.

LOW TEMPERATURES SUPPRESSING THE DEVELOPMENT OF STORED-GRAIN INSECT: It is obvious that, within a certain range, the cooler the grain the safer it is from insect damage. The possibility of changing the micro-climate of a grain bulk by lowering its temperature depends on the availability of cool ambient air. Thus, the ambient air temperature is a limiting factor in the use of aeration for control of insects. Therefore, before reviewing our field experiments on the use of aeration, I shall discuss the threshold limits below which the development of most stored product insects is interrupted.

Different authors have given 17°C as the lower threshold limit at which the normal development rate of most injurous stored product insects is significantly inhibited [1,2]. In Table I a summary is given of the minimal and optimal conditions for population increase of some common stored grain insects. One of the stored product species tolerant of low temperatures is *Sitophilus granarius* L., which takes 100 days to develop from egg to adult at 17°C [3]. *Oryzaephilus surinamensis* L. requires 19°C for a 100-day development period [4]. For *Trogoderma granarium* Everts, a very serious pest of grain, the limit is 22°C [5].

TABLE 1. Optimum temperature for rapid insect growth, and the temperature at which the development cycle takes 100 days on one of the best foods for each species. (From Burges and Burrell, 1964).

Species	Optimum temperature °C	Safe temperature, °C (from oviposition to adult in in a mean of 100 days)
Saw-toothed grain beetle, *Oryzaephilus surinamensis* L.	34	19
Grain weevil, *Sitophilus (Calandra) granarius* L.	28-30	17
Rust-red grain beetle, *Cryptolestes (Laemophloeus) ferrugineus* (Steph.)	36	20
Rust-red flour beetle, *Tribolium castaneum* Herbsi.	36	22
Confused flour beetle, *Tribolium confusum* J. du V.	33	21
Khapra beetle, *Trogoderma granarium* Everts.	38	22
Rice weevil *Sitophilus (Calandra) oryzae* (L.)	29-31	18
Lesser grain borer, *Rhyzopertha dominica* F.	34	21
Flat grain beetle, *Cryptolestes pusillus* (=minutus) Schoherr.	32	19

In grain bulks without active aeration, the initial high post-harvest temperatures are retained for a considerable period of time [6]. In practice, natural cooling of a large bulk of grain is very slow. Even where an aeration system is available, under certain climatic conditions it is not possible to reduce the grain temperature within a convenient period of time. Grain temperatures may remain high for a period of several months [7] and under these conditions there is a risk that a considerable insect population will develop [8]. Therefore, when large numbers of insects are present in the grain, the threshold of 17°C may no longer be safe, and the grain temperature should be lowered to a point at which the cumulative daily heat production by the insects will remain negligible, otherwise, grain temperature is increased due to the liberation of metabolic heat by insects.

In wheat infested with a population of ten weevils (including one adult) per kg of grain, the estimated temperature rise per week is 0.06°C at 17°C [8]. At the peak of infestation in warehouses, densities may reach 1000 weevils per kg [9]. A population of this size may cause rise in the grain bulk temperature of several degrees centigrade per week; these higher temperatures, in turn, may accelerate metabolic activity, causing additional heating of the grain bulk.

It has been suggested that when a considerable insect infestation is present in the grain bulk under cooling, the temperature should be lowered to below 17°C [1]. Temperatures lower than this are effective in causing mortality of certain insect species after relatively short exposure periods. Thus, heat production in the grain bulk caused by insects is decreased considerably.

The most susceptible developmental stages of *Sitophilus granarius* (L.) at 15°C were found to be very young eggs, the prepupae and the pupae [10], exposure to 15°C for 7 weeks resulted in a mortality of over 80% of the population. However, the adult stage of this species is reported to be very resistant and able to survive for over two months at 0°C [11].

To obtain complete mortality of *Tribolium confusum* Duval eggs at an exposure time of 15 days, the temperature should be 5° or 10°C [12]. With *Plodia interpunctella* (Hubner) eggs, complete mortality was obtained after an exposure at 5 hr at 4°C [13]. For *Ephestia cautella* (Wlk.) eggs at 5°C, 20 days of exposure were required for complete mortality [14].

From these figures it is seen that at around 5°C, mortality of a wide range of stored products insect species can be obtained. Conditions enabling reduction of grain bulk temperature to 5°C are available during winter in temperate climates, but when these conditions are not obtainable a refrigeration unit is required. However, since there are relatively cold-resistant species, which are able to survive even in the above mentioned temperatures, cooling of grain by aeration should be aimed at preventing insect infestation development in the grain bulk, rather than at causing mortality to an existing population [15].

LOW TEMPERATURES SUPPRESSING THE DEVELOPMENT OF STORED-PRODUCT MITES: Mites cause heavy losses in stored grain [16]. These pests favor conditions of moderately low temperatures (Table II) and high relative humidities. A monthly mean temperature of 10°C is considered the minimum for the development and reproduction of stored-product mites [16]. When the moisture contents of cereal grains are higher than 14%, conditions are favorable for mite development. Therefore, in grain stored initially with a lower moisture content, mite infestation could be considered negligible.

TABLE II. Approximate minimum and optimum or favorable temperatures at which major storage mites breed. (From Sinha, ref. 16).

	Temperature (°C)	
Species	Minimum	Optimum or Favorable
Tyrophagus putrescentiae	9-10	23-28
Glycyphagus destructor	10,15	15-25
Cheyletus eruditus	12	25-27
Carpoglyphus lactis	15	25-28
Lardoglyphus konoi		23
Aleuroglyphus ovatus	22	23-25
Gohieria fusca		24-25
Rhizoglyphus echinopus	6-10	23-27
Caloglyphus berlesei	16.5	22-30
Acarus siro	7	23-30

ACCLIMATIZATION OF STORED PRODUCT INSECTS TO LOW TEMPERATURES: Insects react in different ways to prolonged exposure to low temperatures. In some species acclimatization to low temperatures can result in increased metabolic activity, while in other species low temperature acclimatization is expressed in an increased ability to tolerate low temperatures.

For example, *Ptinus tectus* Boieldieu, a species known as cold-resistant, showed an increased oxygen consumption when acclimated to 15°C, compared with the same species held at 25°C [18]. On the other hand, in *Tribolium confusum* Duval, the percent mortality at 0°C of adults held at 27°C was twice that of adults acclimated for 4 days to 12°C [19].

The problem of acclimation of *P. tectus* and other cold-resistant species may be encountered in climates in which low embient temperatures prevail throughout most of the year. In this case, there is a possibility to cool the grain bulks to temperatures that will not permit the metabolic activity of cold-hardy insects. However, the problem could become serious by the development of cold resistance in insect species normally requiring high temperatures (such as in the case of the acclimatization of *T. confusum*). This would constitute a drawback to the use of aeration for cooling grain in warm climates with a relatively short cool season.

Further research is required to clarify these phenomena and to evaluate the extent of the problem considering the effectiveness of aeration for the control of stored-product insects.

COOLING OF GRAIN BULKS BY AERATION: I presume that most of the audience here is familiar with the technology of aeration, so I will only briefly mention some elements concerning the aeration system itself. This system comprises a fan, an aeration duct installed in the grain bulk, and a supply duct for conveying air between the fan and aeration duct.

The selected ambient or refrigerated air is moved through the bulk by the operation of the fan. The aeration duct ensures the even distribution of air at a suitable air flow rate. The cooling is achieved by the transfer of heat from the grain to the air moving through it. The most useful air flow rates for cooling the grain bulk are in the range of 3 to 30 m^3/h/ton of grain [20].

Several commercial-scale aeration trials which demonstrate the effect of cooling of grain are summarized herein.

1. Effect of aeration with selected ambient air - A. A trial aimed at eliminating insect infestation under winter conditions in Britain, was carried out by Burrell [15]. A commercial 142-ton bin of dried barley (11.5 - 14.5% moisture content), heavily infested throughout with *Oryzaephilus surinamensis* L. (a mean of 300 insects/kg grain), was cooled by means of a fan supplying air at a rate of 20.4 m^3/h/ton. After intermittent aeration for 400 h the maximum temperature of the grain bulk (38°C) was reduced to between 5 and 16°C. At those points of the bulk where temperatures of 8°C or less were reached, the temperature remained steady for a considerable period. However, at points where the temperature at the completion of cooling was 10°C or more, there was a subsequent rise of approx. 2-5°C, due to the accumulation of metabolic heat from insects. It was concluded that at such heavy infestation, cooling is not likely to destroy all insects unless the grain can be kept cool for a period of many months. B. In a study conducted in Australia by Sutherland [21], a 2700-ton bulk of wheat was aerated with a flow rate of 5.4 m^3/h/ton. Aeration for 1100 h reduced the grain temperature from 31° to 9.5°C. During 3 years of aerated storage there was an almost complete absence of insects. The author pointed out that under suitable conditions aeration can eliminate the need for insecticides. C. A study was made in Israel by us [7], of a bin containing 1142 tons of wheat, aerated at a flow rate of 5.4 m^3/h/ton. The bin was part of a flat storage situated in Haifa Bay. During the first year, beginning in May, the bin received 1212 h of aeration. This air volume lowered the temperature of the grain bulk from an average of 27-32°C to 10-14°C. (Fig. 1). During the summer the grain temperature rose to 18-19°C. During the second winter of storage, 523 h of aeration cooled the grain bulk to an average of 11-14°C.

Samples taken at the start of the observations showed that an insect infestation was already established. The insect

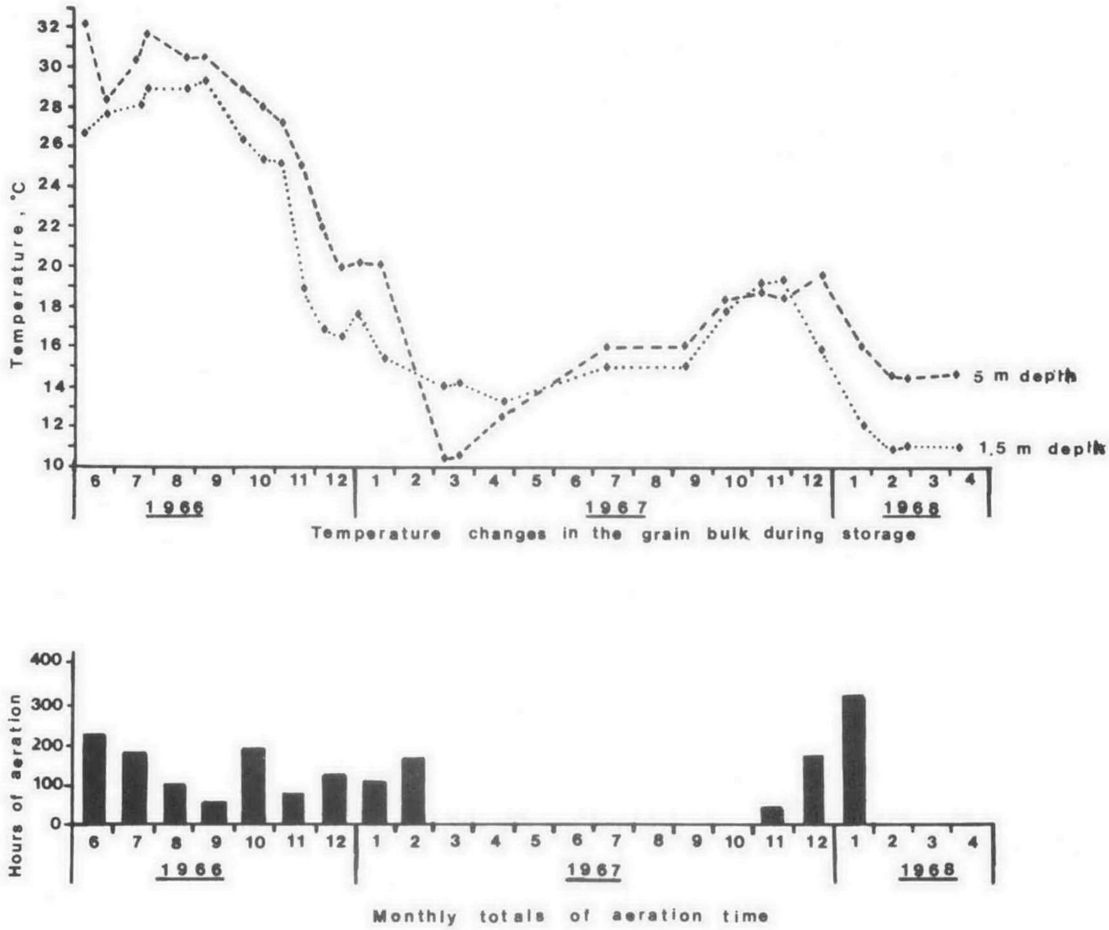


FIGURE 1. The effect of aeration with ambient air on the cooling of bulk grain, trial C, (from Navarro et al., 1969).

species collected from these samples were *Trogoderma granarius* Everts, *Sitophilus oryzae* L. and *Oryzaephilus surinamensis* L. Data on the insect infestations found at the end of the observations, after 22 months of storage, are given in Table III.

Most of the grain-infesting insect species common in this country were dead. However, infestation by the moth *Ephestia cautella* (Wlk.) was found to be concentrated at the surface layer of the grain bulk and also in the aeration duct. Germ-damaged kernels in these regions of the bulk reached 22%, and this was attributed to the activity of moth larvae. Larvae of *Trogoderma granarium* Everts were able to survive the new environmental conditions produced in the grain bulk. Around the aeration duct live mites, mainly of the species *Cheyletus malaccensis* Oud., were recorded.

From these observations it is concluded that the change in microclimate of the grain bulk is effective in arresting the development of the common local stored-grain insects. This charge during the storage period resulted in a change in the live stored-products fauna. Since under the subtropical climatic conditions in which the observations were carried out, mite infestation is

TABLE III. Grain condition and insect infestation after 22 months of storage, in a bulk cooled by aeration with ambient air, trial C Compiled from Navarro et al., ref. 7).

Sampling area	Wheat moisture content (%)	Free insects in grain sample (mean no./kg grain) and percent survival (shown in parentheses)								Damaged grain (%)
		Trogoderma granarium Everts	*Rhyzopertha dominica* (F.)	*Sitophilus oryzae* (L.)	*Tribolium* sp.	*Oryzaephilus* sp.	*Cadra cautella* (Wlk.)	*Cryptolestes* sp.	*Acaridae*	
Surface layer	12.3	3(0)	1(0)	14(0)	3(0)	2(0)	14(0)	1(0)	1(100)	16.3
0.2 - 5-m depth	12.0	3(5)	2(0)	7(0)	1(0)	0(0)	0(0)	0(0)	0(0)	0.4
5 - 9.5-m depth	10.5	15(3)	2(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0(0)	0.5
Aeration duct	12.4	25(0)	0(0)	0(0)	2(0)	1(0)	1(0)	0(0)	50(100)	2.8

not common, this change is reflected by the mite populations found at the surface layer of grain and in the aeration duct.

2. Cooling the grain bulk by aeration with refrigerated air - Although cooling of stored grain by aeration with selected ambient air has been employed successfully, this technique is effective only during a cold season. This has not solved the problem of conservation of grain entering storage in summer.

The use of refrigerated air to maintain the condition of damp grain has been thoroughly examined by Burrell and Laundon [22]. Experimental work was also reported by Sutherland et al. [23], who demonstrated the efficiency of aerating with chilled air to cool dry grain.

In the following we summarize two trials aimed at examining the cooling of dry grain using refrigerated air under Israeli conditions. A. A bin containing 699 tons of wheat was cooled by refrigerated air supplied from a chilling unit [24]. The cooled air was moved through the grain bulk at an airflow rate of 4.6-5.8 m^3/h/ton. The ambient air temperatures over the cooling period ranged from 18 to 31°C (Fig. 2). These temperatures during the cooling period were reduced by the chilling unit to the range of 10-16°C. After 160 h of cooling with refrigerated air, the initial high temperatures of 30-37°C were reduced to 18-19°C.

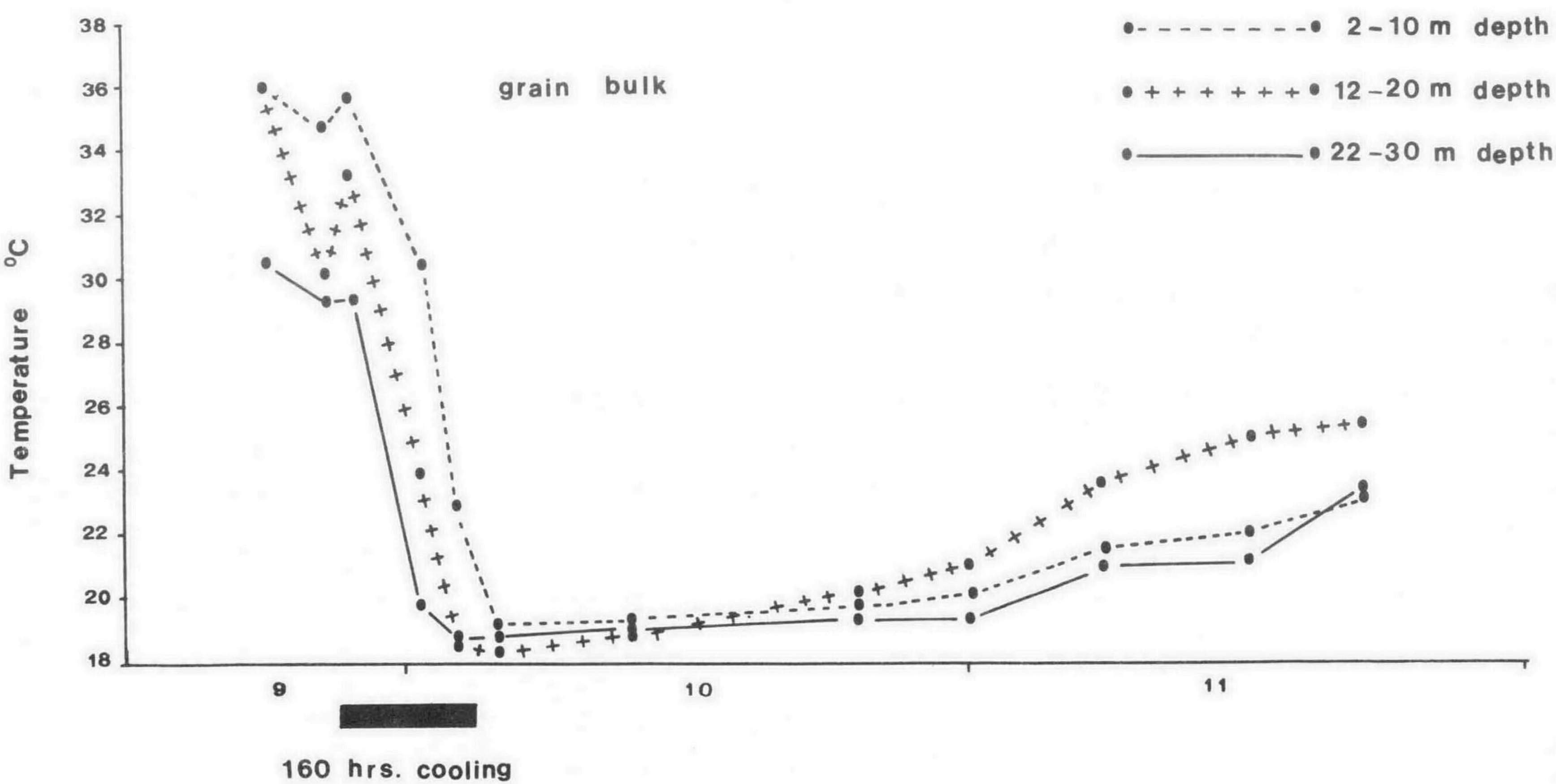
Table IV gives the results obtained on examining the population of the insect infestation found in grain sampled after the completion of cooling. There was a live insect population in the bin, particularly of *Rhyzopertha dominica* (F.). From a comparison of Fig. 2 and Table IV it would appear that the metabolic activity of this population was responsible for the rapid rise in grain temperature after cooling.

At the end of the storage period (approximately 6 weeks after the completion of cooling), temperatures in the upper and lower regions of the bin had risen to an average of 23.5°C, and in the middle region to an average of 25.5°C.

B. In other trials conducted by us, a vertical concrete silo containing 620 tons of wheat was cooled using a chilling unit. The initial temperatures, 30-34°C, were reduced to 15.5-19.0°C by operating the chilling unit for 137 h at an airflow rate of 6.3 m^3/h/ton (Fig. 3).

After 12 weeks of storage the low temperature obtained

FIG. 2 : COOLING PATTERN IN THE GRAIN BULK AND POST-COOLING TEMPERATURES AFTER AERATION WITH REFRIGERATED AIR, TRIAL A. (from Donahaye et al. 1974)



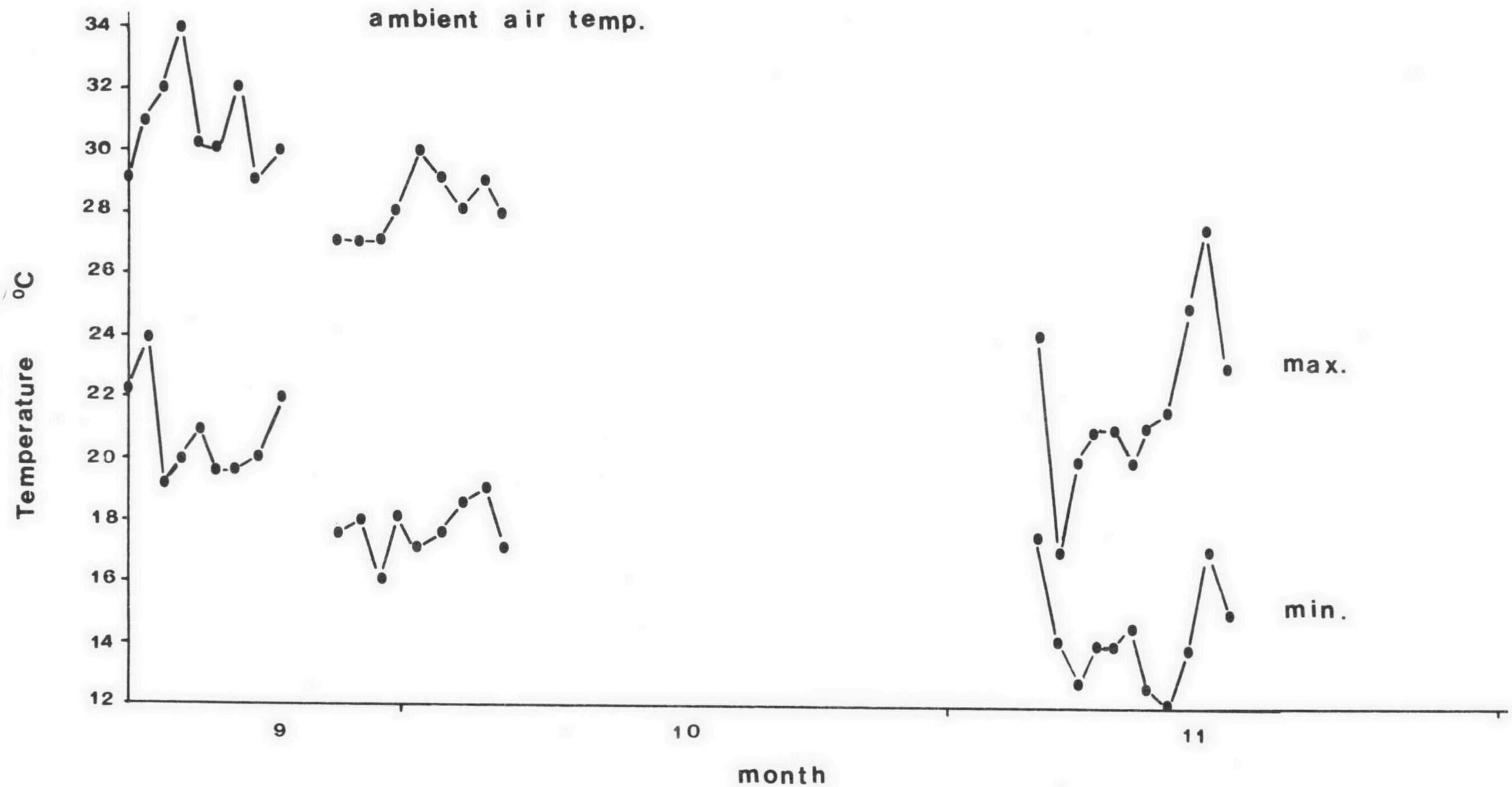


FIGURE 2. Cooling pattern in the grain bulk and post-cooling temperatures after aeration with refrigerated air, trial A. (From Donahaye et al., 1974).

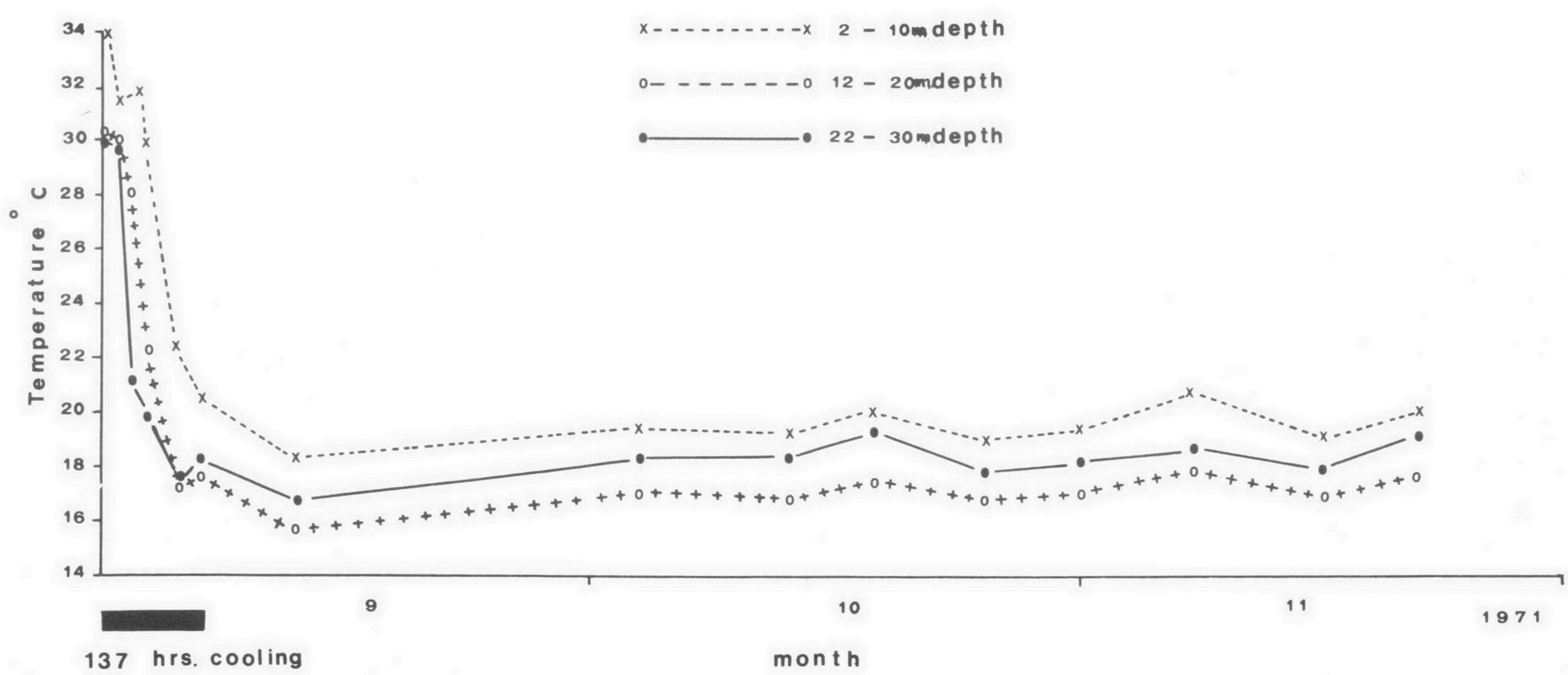


FIGURE 3. Grain temperature changes during storage, in the bulk cooled by aeration with refrigerated air, Trial B.

Table IV. Grain condition and insect infestation after cooling with refrigerated air, trial A. (From Donahaye et al., ref. 24).

Sampling point depth (m)	Moisture content (%)	Free insects in grain sample*			
		Sitophilus oryzae (L)	*Rhyzopertha dominica* (F)	*Cryptolestes* sp.	*Tribolium* sp.
Surface layer	10.4	0 (2)	33 (13)	5 (6)	0 (2)
1.15	10.6	0 (0)	42 (0)	7 (0)	1 (0)
2.30	10.4	0 (0)	40 (0)	6 (1)	0 (0)
3.45	10.6	0 (0)	51 (5)	1 (1)	0 (0)
4.60	10.6	0 (0)	35 (6)	2 (0)	0 (0)
5.75	11.1	0 (0)	35 (4)	2 (0)	0 (0)

* Number of dead insects given in parentheses.

changed only slightly, reaching 18-20°C. In grain samples taken from the bulk, an initial mean population of two insects per kg of grain was found. The results obtained in this trial, compared with the previous one, clearly indicate that cooling is effective in preserving grain from insect damage when the initial insect population is low.

The results obtained so far show that the use of refrigerated air under the climatic conditions described above, is effective in producing a sufficiently cool environment in the grain bulk. The feasibility of applying this storage method should also be considered in other countries with climatic conditions comparable to those under which the above described trials were carried out.

CONCLUSIONS: 1. The lower threshold limit at which the normal rate of most injurious stored-product insects' development is suppressed, is 17°C.

2. Aeration with ambient air is effective in cooling grain and in maintaining low temperatures in temperate climates.

3. Cooling dry grain with refrigerated air was found to be efficient in a warm climate.

4. There was a clear indication that for bins heavily infested the grain requires cooling to temperatures lower than 17°C, to prevent rapid rewarming and further damage to the grain bulk.

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