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AERATION OF GRAIN WITH AMBIENT OR ARTIFICIALLY COOLED AIR : A TECHNIQUE TO CONTROL WEEVILS IN TEMPERATE CLIMATES*

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ABSTRACT

Recent research on ambient aeration for grain preservation has concentrated on achieving temperatures near freezing point by blowing natural cold air after bin loading, at all periods when the difference in temperature between the grain and the ambient air is superior to 7°C.

In the experimental grain bin (35 tonnes), insect-proof small containers, filled with infested wheat at all stages of Sitophilus granarius, were set at different locations during loading. Each time there were good cooling conditions, the fan was manually switched on. The temperature of the grain decreased from 28 to 20°C during the first week after harverst, and to 15°C after the second month of storage. Then, the temperature in the grain mass was brought as low as - 1°C at the beginning of the winter season. Four months later the grain temperature reached again the 7°C level due to natural reheating.

After a 10.5 month storage period (unloading the bin the end of spring), the grain temperature was only 14°C. At that moment, a very few insects were still alive (0,6 % of the total population which reached maturity).

Separately, it was observed after a laboratory trial carried out at a constant temperature level of 7°C, that S. granarius cannot survive longer than 3 months.

Nevertheless, the efficiency of this physical treatment is almost equivalent to a chemical disinfestation without any risk of residues or protection failures compared to some situations of long term storage with the preventive application of a persitent insecticide.

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INTRODUCTION

Aeration, whereby ambient or artificially cooled air is used, is primarily a grain preservation technique (Burges and Burrel, 1964 ; Berhaut and Lasseran, 1986 ; Brunner, 1986 ; Armitage, 1987). The effects being sought are numerous :

(a) To preserve the technological properties of the grain at a standard resembling the initial stage (that at harvest time) as closely a possible (baking quality, vitality, etc...) (Burges and Burrel, 1964) ;

(b) To limit the development of the storage microflora, the principal cause of damage to the grain (Brunner, 1986);

(c) To diminish the loss of dry matter by reducing the temperature so as to minimize or reduce the respiratory activity to zero ;

(d) To avoid water and heat being released within the storage bin, in order to eliminate the risk of hot spots (Foster and Tuite, 1982) ;

(e) Finally to prevent insects from multiplying by bringing the temperature of the grain down to below 12°C, the threshold at which their reproductive activity is inhibited (Burges and Burrel, 1964 ; Granovsky and Mills, 1982 ; Armitage, 1987 ; Fleurat-Lessard, 1987 ; Lasseran and Fleurat-Lessard, 1988).

Technicians in charge of commercial grain stores are well aware of these effects. Nevertheless we are still coming up against certain obstacles. This is either because aeration equipment is non -existent, has a low capacity (is badly designed), is without a temperature monitoring system - the "compass guide" of aeration -, or is badly managed by the users. The main difficulty is getting users to accept the fact that it is possible to aerate at night - this being the best time as far as the outside temperature is concerned and also because of the cost of electricity - despite the rise in the relative humidity of the air. Yet I.T.C.F. has shown that this relative humidity is only a minor factor, since the air being used is colder than the grain and so there is no reason to worry about rewetting (Berhaut and Lasseran, 1986).

When considering aeration, it is often forgotten that equilibration of the grain temperature to that of the air happens at a speed 50 to a 100 times greater than hygroscopic equilibration : roughly 800 m3 of air are needed to cool 1 m3 of grain, and 50,000 to 60,000 m3 to dry or rewet it, depending on the relative humidity of the air blown into the grain (Lasseran, 1988).

In order to sum up the usefulness and management of the aeration, the well-known chart on cereal preservation, set up by Burges and Burrel (1964) (figure 1), was completed by an aeration guideline chart (figure 2) (Lasseran, 1988).

So as to be completely aware of the long lasting effects of low temperature cooling on the quality of the grain, but especially on the development and eventual mortality rate of a population of insects and hidden forms, a trial was carried out with the co-operation of the INRA Laboratory of Stored-Product Entomology, near BORDEAUX. This experiment seemed useful, for during preceding trials the weather conditions in December, January and February enabled us to cool the grain to well below the 12°C level. In addition, a laboratory trial on cold hardiness of Sitophilus granarius (L.), the main insect pest in the Northern part of France, was carried out.

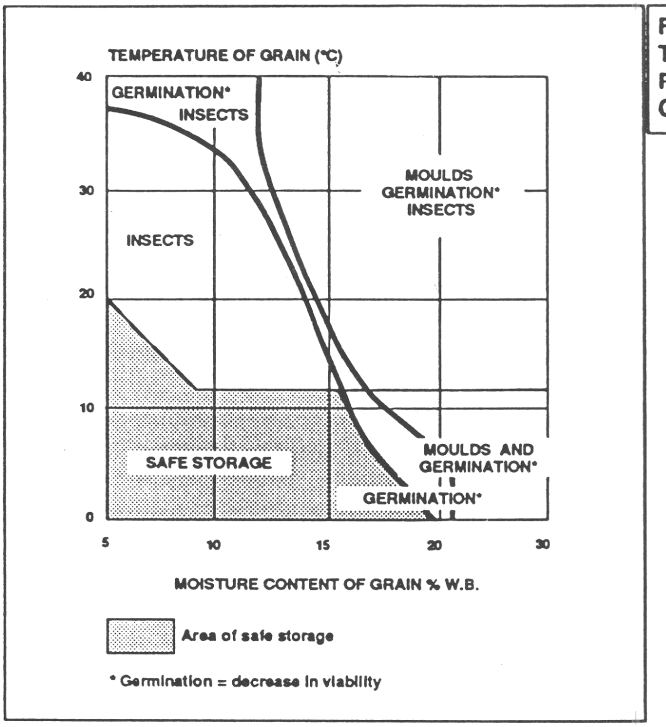

FIGURE 1 : CEREAL PRESERVATION CHART IN TERMS OF TEMPERATURE AND MOISTURE CONTENT OF THE GRAIN.

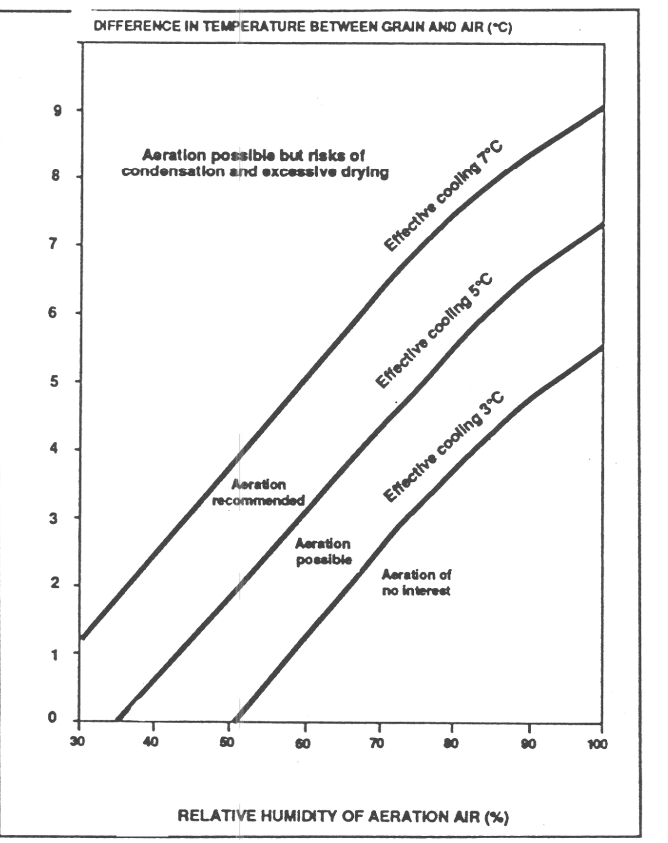

FIGURE 2 : AERATION GUIDELINE CHART FOR CEREALS AT STANDARD M.C. (16 % W.B.) ITCF (LASSERAN, 1988).

MATERIALS AND METHODS

The storage trial took place in a building where we had at our disposal a round metal bin fitted out with a perforated false bottom for distributing the air used in the aeration procedure. The dimensions are as follows :

. diameter : 3.28 m

. available height over the false bottom : 5.5 m

. useful total volume : 46.5 m3

. capacity : about 35 tonnes.

Before beginning the trial, the bin was cleaned, but was not treated with a pesticide. The dust was swept up, then vacuumed.

The batch of grain was composed of malting barley of the Menuet variety. It was put into the bin, at the harvested moisture content, that is to say 13.25 % (W.B.), uncleaned and at the temperature recorded at harvest time of 28.1°C.

In order to reduce the temperature of the grain progressively, the night time cooling stages covered the period between harvest and the cold winter time.

The bin was fitted out with 3 thermometric probes, each one containing 3 sensors, so as to follow the change in the temperature of the grain, as shown in figure 3.

The grain was removed from the bin after being kept for nearly one year, without having undergone any pesticide treatment.

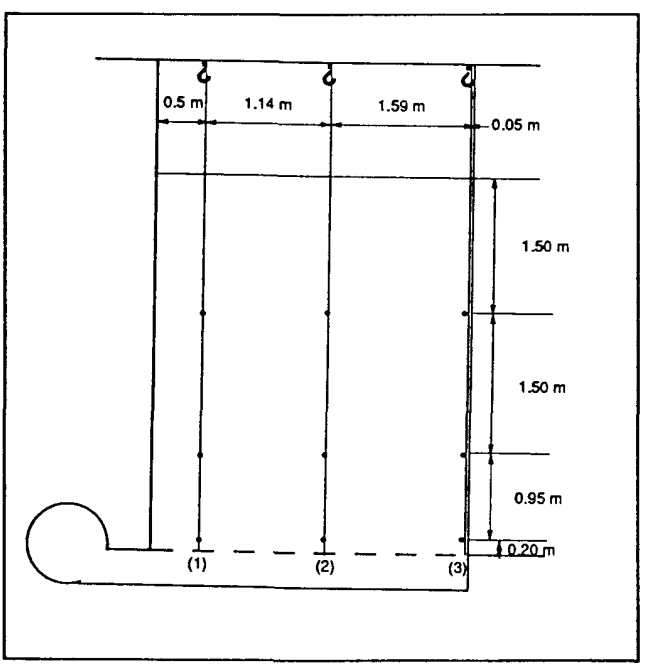

FIGURE 3 : POSITION OF THE 3 PROBES AND 9 TEMPERATURE SENSORS IN THE GRAIN

The study made on the effects of cold on the development of insects was carried out during this storage year. Before filling the bin with barley, small containers which were insect-proof but permitted the circulation of air were installed in six different places in the bin (figure 4). These containers enclosed 250 g of dry wheat infested with 10 adult weevils (*Sitophilus granarius*) and 100 hidden forms (eggs and larvae).

The containers were put in place on the 31 st July 1984 and removed from the bin on the 24 th June 1985. A first count of the adults, alive or dead, was made on the 26 th June 1985. Then samples were put into an incubator at 25°C and 70 % relative humidity, in order to study the development of adults resulting from the hidden forms : each container was checked six times at about 10 day intervals.

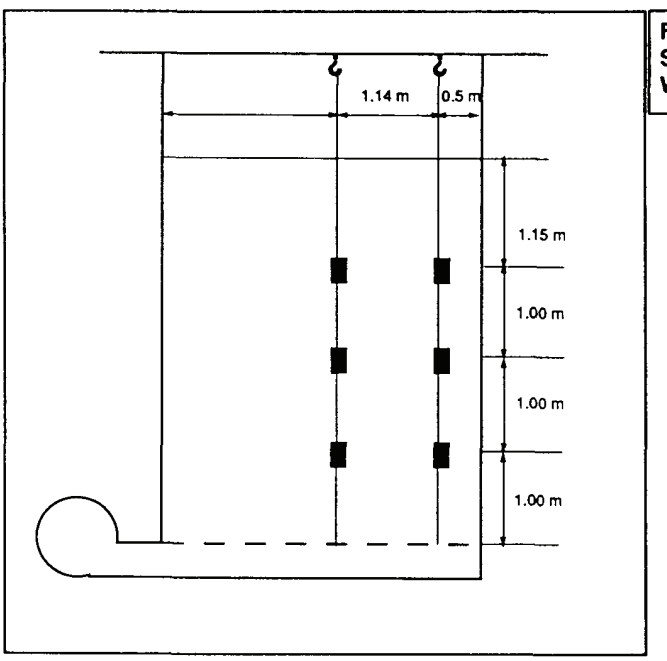

FIGURE 4 : POSITION OF THE 6 SMALL CONTAINERS FILLED WITH WEEVIL INFESTED GRAIN

The laboratory trial was conducted on wheat infested by all developmental stages of S. granarius. It was carried out in a climatic chamber regulated at 7°C (± 0,5°C) which was the average level of temperature during the previous field trial run with cold air aeration on barley (Berhaut and Lasseran, 1986). Isolation of each stage of S. granarius was realized from radiographs of heavily infested wheat, during a 6 week period, by young weevils. A second radiograph on separate stages was used to confirm a correct identification. Isolated stages were divided in four batches corresponding to the different conditions of exposure :

- the control was incubated at 18°C and 75 ± 5 % Relative Humidity (R.H.) ;

- and three other samples of infested wheat were exposed at 7°C during 60, 77 and 90 day time periods, without any acclimatization.

After the exposure period, the infested grain was incubated at 20°C and 75 % RH as the control, and regularly sieved every 3 or 4 days (2 twice a week) to observe the weevils' emergence. After a long period without emergence, when all live stages had completed their development, a new radiograph was taken to observe the level of evolution of initial stages. The Emergence Reduction Rate (ERR) was determined for each stage and corrected with control results.

RESULTS AND DISCUSSION

1) Change in the temperature of the grain

During the storage year the mean temperature of the barley decreased from 28.1°C at harvest time on the 31st July 1984 to - 1.2°C after the 5 th aeration 'dose' (1) on the 7 th January 1985. This first period of 5.4 months represents the cooling phases of the grain mass in stages ; then during a second period lasting 5.6 months we observe a slow natural reheating from - 1.2°C to 13.8°C that is to say a rise in temperature of 15°C (figure 5).

Five 'doses' of night-time aeration were needed to obtain this minimum in temperature. They were carried out in practical conditions resembling those applied in storage plants or by farmers. The first dose was administered at the moment of harvest, then, for the four other doses, as soon as the difference in the temperature between the outer air and the grain appeared to remain constant around 7°C.

During the night the characteristics of the air (temperature and relative humidity) are not constant and even more so for several nights. So before deciding to start aeration, it is essential to contact the local weather forecasting station for full information on the temperatures expected on the following nights. The aeration can also be carried out automatically by using a thermostat : the operator sets the temperature threshold to a level corresponding to the mean temperature of the grain batch, reduced by 7°C.

Each time a 'dose' of aeration is administered, the air blown in begins by cooling the layers of grain located in the lower part of the bin. A transition zone is created where the cooling takes place before progressing slowly in the direction of the air flow.

In this way all the layers of grain (going from the bottom to the top of the bin) are cooled successively. The aeration is stopped when the temperature of the upper layer reaches that of the lower layers, to within 2 or 3 degrees C.

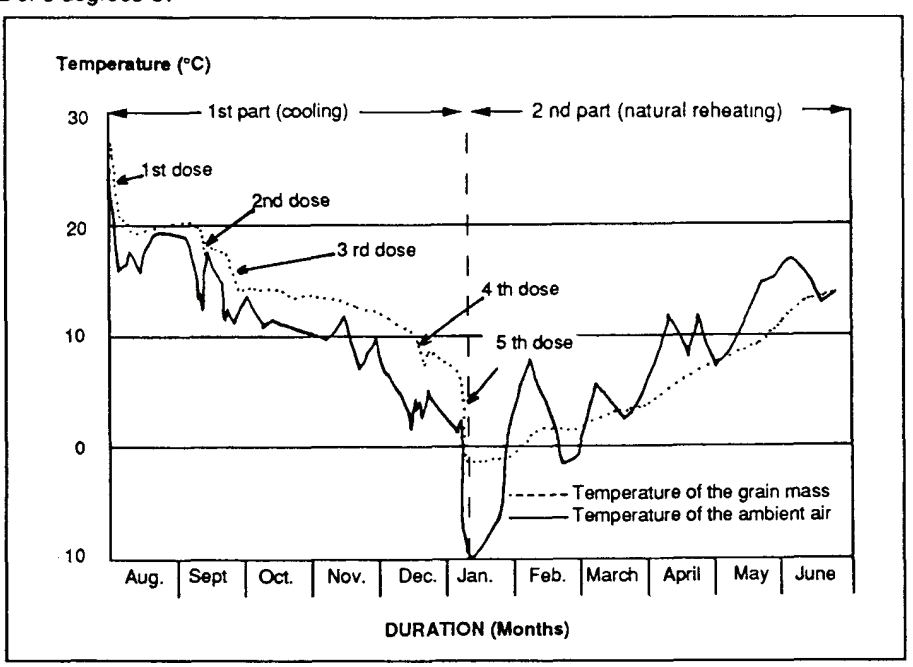

FIGURE 5 : CHANGE IN THE TEMPERATURE OF THE AIR AND GRAIN DURING THE STORAGE YEAR

(1) - Dose' of aeration : cumulated quantity of cold air introduced into the grain over a short period to cool the grain mass.

The storage year can be divided into two parts (figure 5) :

• the first part during which the temperature of the ambient air and the grain drops. This period goes from harvest time to the last aeration dose in January 1985. The temperature of the grain is higher than that of the ambient air, and remains higher than 12°C from harvest time up to the end of November, that is to say over a period of a little less than four months. It is only during this time, which varies from year to year, that the insects can develop, since according to a lot of previous works done by entomologists, insects are sexually inactive below the 12°C threshold.

• the second part, from January 1985 to June 1985 during which the ambient temperature rises slowly but progressively, the temperature of the grain being nearly always lower than that of the air. The temperature of the grain once again reaches the 12°C threshold during the first week of June, that is three weeks before the bin is emptied.

Apart from during the phases of aeration, the temperature of the grain which is located along the bin wall, at about 5 cm from it, is the same as that of the air (to within a few degrees) measured in the shed where the bin is installed. During the first part of the trial when the bulk of grain is being cooled progressively, the temperature in this area is lower than the mean temperature of the grain ; during the second part, when the bulk of grain is being reheated progressively, from the end of winter, the temperature in this area is higher than the mean temperature of the grain. While the former rises slowly by about one degree C every ten days, the temperature of the grain which is in direct contact with the metal wall closely follows the variations in the temperature of the air inside the shed.

2) Change in the insect population

The increase in the number of insects found dead or alive in the samples before and after incubation could only have occurred at the beginning or possibly at the end of the storage period, when the temperature of the grain was higher than 12°C. The insect-infested samples developed in a different way, depending on their position in the bin (table 1) :

• in the three samples placed along the edge of the bin, the analysis revealed fewer insects having reached maturity, than those in the centre (212 along the edge as opposed to 744 in the centre). This indicates that an arrest in development occurred later in the central part than in the peripheral zone. This can be explained in the following way : the temperature of the grain stayed higher for a longer time in the centre of the bin than towards its periphery. The temperature of the grain located at 50 cm from the bin wall dropped below 12°C towards the 19 th November 1984, whereas in the central part it fell below this threshold only on the 11 th December 1984, that is to say three weeks later.

• the higher the samples of infested grain located in the centre are placed, the more insects they produce. At the final check, going from the bottom to the top, they produced 65, 258 and 421 insects. This result can be explained by the fact that the temperature of the grain at the top of the bin was higher than that of the grain located lower down.

The increase in the number of adult insects in the samples corresponds to two successive stages :

• firstly, the development of tne 100 insects which were present as hidden forms when the containers were put in place,

• then the multiplication of the ten first generation adults originally present, possibly added to by the reproduction of mature individuals coming from the hidden forms.

At 25°C about 45 to 50 days are needed for a weevil population to produce a second generation of adults. This length of time is increased if the temperature drops (between 12 and 20°C). In our trial, the grain only reached the threshold of 12°C at the end of 120 days. In these conditions it is obvious that, before the grain cooled, the first generation had time to multiply in the containers located in the centre of the bin, or, more precisely, half way up and at the top of the pile, since 258 and 421 adult insects respectively were counted there.

By way of comparison, identical samples to those put into this bin, but preserved in the laboratory at 16°C, had to be destroyed after a nine month period, because the number of insects approached 4000 individuals per infested sample in insect-proof containers.

After a one year preservation period it was amazing to observe that the adult insects were all dead at the first check carried out immediately after emptying the bin. Adult insects in a state of hibernation die if exposed to prolonged bouts of cold. As for the hidden forms, some of them develop during the incubation, but the majority die immediately, the result of a long stay in cold conditions shortly after they reach maturity being fatal to them. However they are not completely destroyed, for about 0.6 % withstand the cold. According to entomologists this denotes the remarkable effectiveness of cooling by aeration which is far superior to the effect of a pesticide treatment based on chemical products. This preventive method of grain preservation avoids the risk of contamination by insects remaining alive inside the storage building, but outside the grain bin : cold grain repels insects which is not so with grain stored at higher temperatures when toxic residues become ineffective, a long time after an insecticide treatment was applied.

DATES OF SCREENINGS	SAMPLES OF INFESTED WHEAT					
	CENTRE TOP	CENTRE MIDDLE	CENTRE BOTTOM	EDGE TOP	EDGE MIDDLE	EDGE BOTTOM
26/06 (1)	411 D	256 D	64 D	50 D	114 D	43 D
05/07				0 D + 2 L		
16/07	4 D	1 D	1 D	1 D		0D + 1L
26/07 (2)						
09/08	2 D + 3 L			1 D		
16/08	1 D					
27/08		1 D				
TOTAL	418 D + 3 L	258 D	65 D	52 D + 2 L	114 D	43 D + 1 L

D : Dead insect
L : Live insect

(1) First screening : after emptying the bin
(2) other screenings : after incubation

TABLE 1 : RESULTS OF ENTOMOLOGIC CHECKS MADE WHEN THE BIN WAS EMPTIED (1st screening) AND AFTER INCUBATION (other screenings).

Nevertheless, the level of 99,4 % ERR in the full scale trial, at the center of the bin, is sufficient to destroy the capacity of multiplication of the population over a short term storage period, reducing the rate of S. granarius infestation by a 100 factor.

3) Moderate cold tolerance of S. granarius in laboratory trial

Full-grown larval instar (4 th) is the most tolerant developmental stage of S. granarius to moderate cold exposure (figure 6). The 3 rd larval instar and pupae have also a good tolerance to cold, some individuals remaining alive after 77 and 60 days of exposure time respectively. Nevertheless, after a 90 day exposure period, no adult live weevil is observed.

It is pointed out that the temperature remained absolutely constant during exposure periods and that no acclimatization or slow decrease in temperature was made before cold exposure. It was the opposite in the applied field trial presented above.

The granary weevil is known for its good tolerance to prolonged periods at cold temperatures (0 to 2°C). But, during a long period of exposure to moderate cold (7°C), without feeding or moving activity, the lethal effect is almost the same, however with a small dependence on the temperature level : the insect dies after complete consumption of all its energetic reserves from an initially fat body. At the 7°C level, slight respiratory activity might still remain, and this should explain why the tolerance to cold is sometimes better for insects maintained at a low level of temperature, such as 2°C, than at a moderate low level (7°C) as in our trial.

In the applied field trial, the temperature of the grain mass stayed under the 7°C level from early January to late April, i.e. nearly 4 months, and some insects are still alive at the end of the storage period. This should be related with the observations on the laboratory trial, for the temperature of the grain mass reached - 1.2°C and was kept 2 months below 2°C.

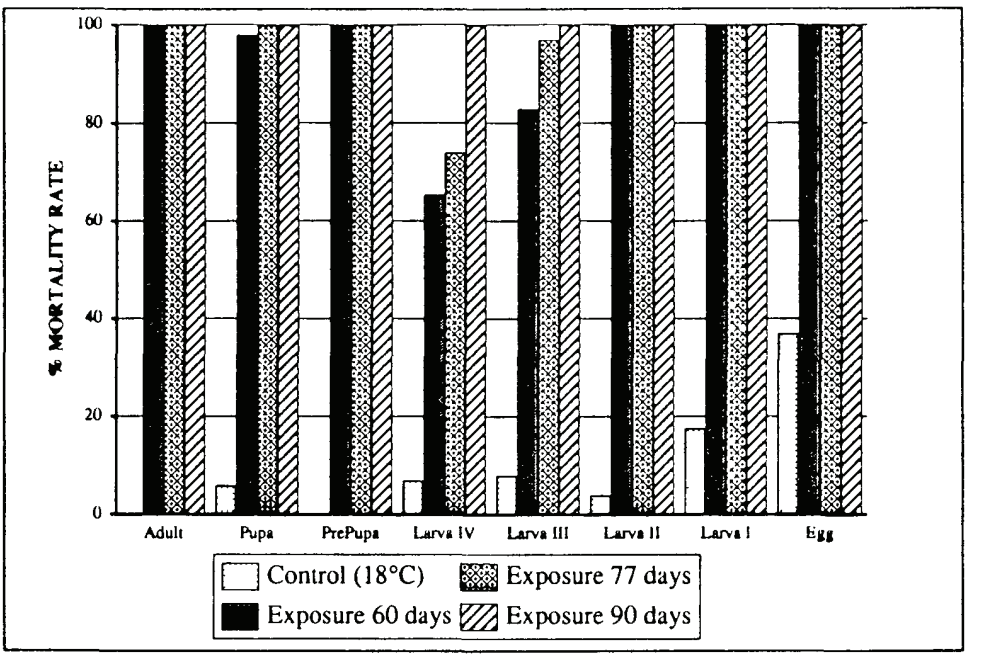

FIGURE 6 : COLD SURVIVAL OF S. GRANARIUS : TOLERANCE OF DIFFERENT STAGES AT 7°C

CONCLUSIONS

Several lessons can be drawn from these trials.

1. Aeration can be regarded not only as a technique for preventing insects from multiplying, but also as a disinfestation technique, if winter weather conditions permit it.

2. Cold kills S. Granarius if the storage temperature can be kept below 7°C for at least 3 months. This result could be extented to S. Oryzae and S. Zeamais, but at a temperature not exceeding 10°C.

3. The risk of chemical residues is totally suppressed when selling, processing or consuming the grain.

4. If, for commercial reasons, we want to ensure the standard specifications of 'no live insect' a shock effect chemical treatment with dichlorvos (D.D.V.P.) may be warranted at the time of dispatching the grain, for we have seen that a few individuals (less than 1 %) manage to withstand the cold.

5. Artificial cooling (chilling) can make it possible to reach the threshold of 7°C (or of 10°C), more rapidly and so keep grain stocks below this degree for a longer time, either during a mild winter or in areas where the winter temperature remains mild. The choice of the chilling technique should take into account other criteria, particularly the effects on grain quality, besides just that of insect control.

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VENTILATION DU GRAIN PAR AIR AMBIANT OU PAR AIR REFRIGERE / UNE TECHNIQUE DE LUTTE CONTRE LES INSECTES EN CLIMAT TEMPERE

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RESUME

Les recherches récentes sur la ventilation par air ambiant visant la préservation du grain se sont concentrées sur l'obtention de températures avoisinant le point de congélation de l'eau, grâce à de l'air froid naturel insufflé après le remplissage des cellules, pendant les périodes où la différence de température entre le grain et l'air ambiant est supérieure à 7° C.

Dans la cellule expérimentale (35 tonnes), de petits conteneurs étanches aux insectes, remplis de blé infesté à tous les stades de croissance de *Sitophilus granarius*, ont été placés en différents endroits pendant le remplissage. chaque fois que les conditions de refroidissement étaient favorables, la soufflerie était mise en marche manuellement. La température du grain s'est abaissée de 28 à 20° C au cours de la première semaine après la moisson et jusqu'à 15° C après le second mois de stockage. La température de la masse du grain s'est abaissée à -1° C au début de la saison d'hiver. Quatre mois plus tard, cette température remontait à un niveau de 7° C en raison du réchauffement naturel.

Après une durée de stockage de 10,5 mois (vidange du silo à la fin du printemps), la température du grain était seulement de 14° C. A ce moment, très peu d'insectes étaient encore en vie (0,6 % de la population totale ayant émergé des conteneurs témoins).

Par ailleurs, après un essai en laboratoire entrepris à un niveau de température constant de 7° C, on a observé qu'une souche française de *S. granarius* ne pouvait survivre plus de trois mois dans ces conditions.

L'efficacité de ce traitement physique est presque égale à celle d'une désinfestation chimique, sans risque de résidus ou de défauts de protection pouvant se manifester dans les situations de stockage à long terme avec pulvérisation préventive d'un insecticide persistant.