Quality enhancement of stored grain by improved design and management of aeration

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Abstract

Aeration is the right preservation technique for all grains in order to control all quality criteria and reduce running costs in storage facilities if associated with a temperature monitoring system. Very often warehouses are poorly equipped and/or badly managed with regard to aeration because of a lack of practical knowledge leading to preconceived ideas. The air feeding network (pipes and ducts) has to be properly designed to minimise pressure drops for an appropriate air flow rate (5–15 m^3/hour/m^3). The fan (centrifugal in most cases) must be selected to satisfactorily work on any species of grain (rape, barley, wheat, rice, maize, sunflower, soybean etc). The working mode of the fan (blowing or sucking) is of prime importance; a rise in static pressure of 850 Pa will generate a 1°C increase in temperature. Usual static pressures range from 2–8 kPa. So, apart from bins or stores of small height, it seems technically wiser to have a suction fan aspirating the fresh air at the top of the bin and throwing out the used air at ground level in order to avoid compression and obtain better benefit from cooler periods. Grain has to be aerated several nights in succession during 4–10 favourable hours per day, i.e. on both sides of the daily minimum, the fan being controlled by a temperature regulator. Since this procedure has been questioned experiments were carried out during the 3 last years, in close cooperation with the INRA Research Centre of Bordeaux, in a medium size metallic bin (500 t, height 16 m). They have shown that under temperature climates 2 or 3 aeration periods, from summer to autumn, are sufficient to cool the grain from 30–5°C or less. Afterwards, grain temperature remains stable during winter, and slowly rises in the spring. Tests applied to grain stored for one year showed an excellent hygienic condition, no marked local rewetting even when aerating with a high relative humidity, no chemical change, a slight increase in the technological criteria of quality, and last but not least, a total disinfection in the case of an initial pest infestation: this means chemicals are not needed, a great advantage for store operators (no insecticide expenditure), millers and consumers (no risk of residues). These observations have been confirmed by checks made on wheat stored in large round concrete bins (diameter 9 m, height 40 m, capacity 2000 t).

Introduction

The optimisation of an aeration system rests in the first place on well designed installations (Lasseran 1988). The air feeding network (pipes and ducts) has to be properly calculated to minimise pressure drops for an appropriate airflow rate (5–15 m^3/hour/m^3). The fan (centrifugal in most cases) must be selected to satisfactorily work on any species of grain. The choice of ducts is also an important question (Lasseran 1993).

The objective of this paper is to take another look at regular aeration (no chilling unit involved) in order to preserve all quality criteria of grain by improving the design and use of the technique. Furthermore, so as to take into account international trade regulations on chemical residues, and meet consumer requirements for sound and healthy foods, the paper will stress the limitation of insecticides, which is a worldwide concern (Cuperus et al. 1993).

Grains harvested or dried at commercial moisture levels (14–15 % w.b.) and at temperatures as high as 20–35°C cannot be preserved during a long-term storage period if they are not cooled to at least below 12°C. Otherwise, they are liable to be damaged and/or tainted by (1) storage microflora (mainly moulds) and possibly mycotoxins, (2) insects and mites, the most dangerous being the granary weevil, *Sitophilus granarius*, (3) enzymatic reactions leading to dry matter losses, decrease in viability, lowering in breadmaking qualities, etc.

Recent findings (Lasseran et al. 1990) on cold survival of *Sitophilus granarius* at 7°C have shown that all stages (eggs, larvae I, larvae II, prepupae, pupae and adults) are killed after 2 months exposure; larvae III and larvae IV are more cold-resistant, as indicated in Figure 1, but die after a 3-month exposure. As these experiments were carried out without acclimation to cold, it seems wiser, in practice, to work from a 4–5°C lethal level.

With regard to aeration, a high relative humidity of the cooling air is not a major inconvenience: the risk of locally rewetting the grain is very limited if the difference in temperature between grain and air is greater than 5°C. Thus, aeration at night or early in the morning, when the ambient air temperature is lower, is more efficient and cheaper (electricity night rate).

When a fan's static pressure exceeds 2 kPa (e.g. wheat aerated in a bin higher than 15 m, with an airflow rate of 10 m^3/hour/m^3), air temperature is increased by 2°C, for 3 kPa by 3°C, etc. When blowing air through the grain mass, the fan compresses and heats the cooling air: this disadvantage is suppressed when air is sucked from top to bottom of the bin by a fan at ground level. This method of operation permits the maximum cooling potential of the ambient air, which is important in subtropical or mediterranean type climates. Contrary to non-experimentally based assertions, the small perforations in the sheet-steel of air ducts do not get blocked up by grain particles when aspirating the air.

Cooling of the grain can be divided into 2 or 3 aeration cycles, from harvest season in summer up to the end of autumn.The goal is to rapidly reach the 12°C level in the grain mass to prevent insect reproduction, and then to continue to cool to near 8–10°C, possibly 4°C, to kill any living pests. Each cooling cycle is also divided in several steps cumulating the coldest hours of various days in succesion. With an airflow rate of 10 m^3/hour/m^3 of grain, the total cumulative time of aeration is about 100–120 hours, e.g. 12 to 15 nights at the rate of 8 'favourable hours'/day (Fig. 2).

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Materials and Methods

A 600 t metallic storage bin (Fig. 3), 16 m high, horizontal cross-section 6.42 × 6.42 m, filled with freshly harvested wheat, equipped with a 6.5 kW centrifugal fan (airflow rate: 7 m^3/hour/m^3) controlled by a thermostat for automatic running when ambient temperature is lower than the setting point, has been used for a long-term storage experiment. A fan sucked in fresh air at the top of bin and emitted the used air at ground level, since the static pressure was 3.3 kPa. The storage time was 300 days (mid-August 1992 to mid-June 1993).

A bin temperature monitoring system (5 cables, 6 sensors in each), a computer and a printer were used to measure and record grain temperatures throughout the storage period. A set of 12 small grain cages (0.5 dm^3) infested with all stages of *S. granarius* (25 adults and 100 hidden forms) were fixed on two cables, in the centre and a corner of the bin.

After the first cooling cycle is achieved (thermostat setting point 18°C), the threshold is adjusted on a new setting point (12°C) for the second cycle, and finally 2°C for the third cycle (Fig. 4). In practice such a low setting is not needed, 5°C is sufficient, but the aim was (1) to verify the influence of cold on insect mortality or survival, (2) study grain natural reheating in the spingtime.

Results and Discussion

Grain temperature during the storage period (Fig. 5)

Grain is rapidly cooled to 17°C in summer after harvest due to the important diurnal-nocturnal difference in temperature (10–12°C on average, Fig. 2). Then, to 8.5°C in early autumn,

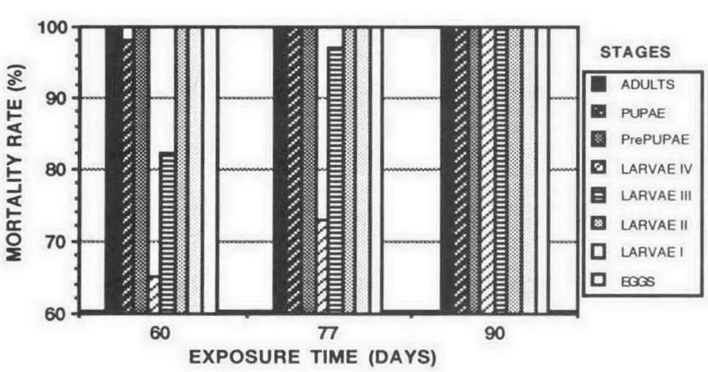

Fig. 1. Mortality rate of *Sitophilus granarius* at 7°C (without acclimation) as a function of exposure time.

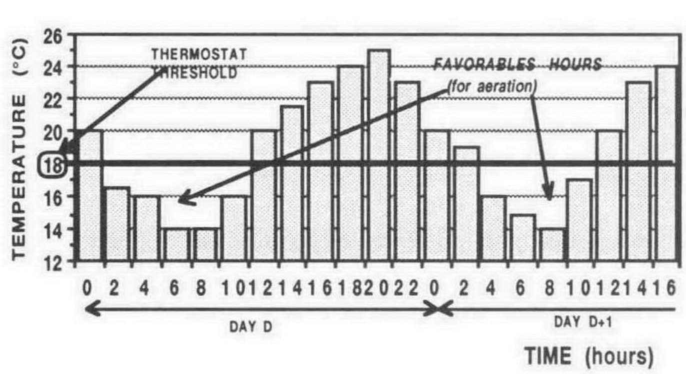

Fig. 2. Typical summer weather (Orléans, France) and 'favourable hours' for aeration

finally to –2°C just before winter. After a 300-day storage time, grain temperature rises slightly to +2°C in the centre of the bin (3.2 m from walls), and more markedly to 14°C near the edge (0.6 m from walls).

Grain moisture content

No significant overall change was observed: 12.4%wb at bin loading, 12.8% at emptying. A light local rewetting was noted on the grain surface only, with a maximum of 16.8% at 0 to 0.3 m depth, then a fast decreasing gradient was seen to 1.50 m.

Microflora (bacteria and moulds) (Table 1)

A decrease in the total number of bacteria and moulds was noted: this disinfection is an important advantage for the milling industry since the International Commission on Microbiological Specifications for Foods recommends the limit of wholesomeness at 10^4 mould propagules per gram. Furthermore, no mycotoxins were detected in the samples taken when emptying the bin.

Table 1. Evolution of microflora

Microflora	Bacteria Nb/g	Moulds Nb/g
Loading	1.2 106	12.9 103
Unloading	0.3 106	5.25 103

Insects (*Sitophilus granarius*, granary weevil)

The rate of mortality of the insects confined in the cages was 100% at the centre of the bin and 98.8% at 0.60 m from the walls. Surprisingly, the total number of dead insects in the cages after the experiment ranged from 25 to 60 individuals, though they were initially 125, and potentially 250 after a 60-day storage period before the temperature dropped below 10°C: clearly, the first cooling cycle which brought the grain temperature to 17°C in two weeks markedly disrupted the hatching of the larvae.

No insects, dead or alive, were found in the rest of the grain. This suggests that moderate cold as it was the case at the beginning of the trial is sufficient enough to prevent insects from invading sound grain, and that aeration is more effective than chemical insecticides in controlling insects.

Breadmaking quality of wheat (Table 2)

No significant change was observed between bin loading and unloading with regard to various conventional tests: Zeleny, Chopin alveogram, French breadmaking mark, Hagberg falling number.

Table 2. Evolution of breadmaking quality

Breadmaking quality of wheat	Zeleny (mL)	Hagberg (seconds)	French breadmaking mark/300
Loading (17/08/92)	49	356	178
Unloading (14/06/93)	45	441	179

Cost of aeration

The specific electricity consumption measured for each aeration cycle is 2.5 kWh/t, leading to the practical ratio of 5 kWh/t for 2 cycles. As night (off-peak) electricity is cheaper,

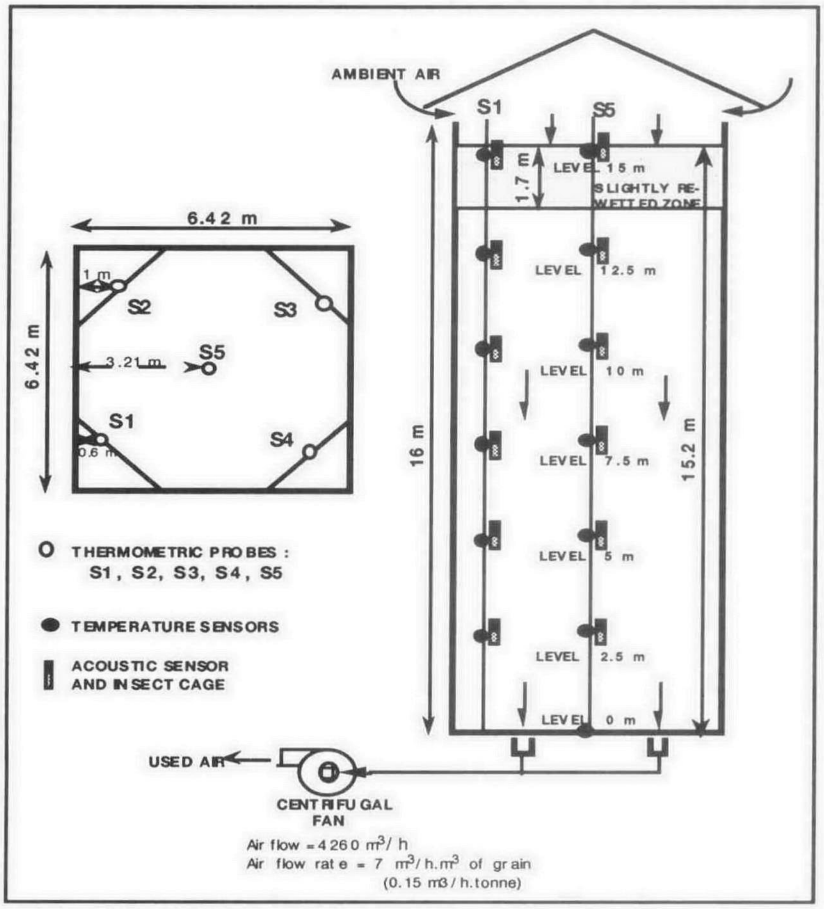

Fig. 3. Diagram of the experimental bin used for aeration trials

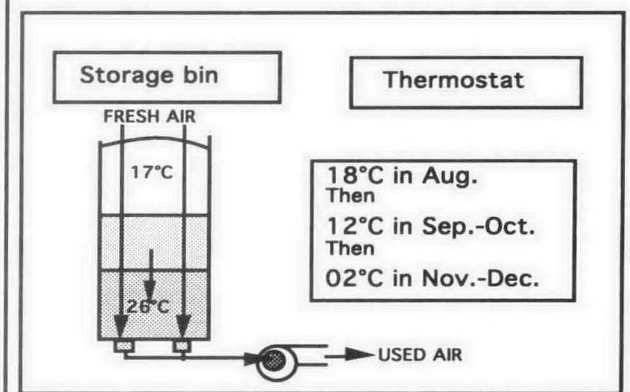

Fig. 4. Scheme of aeration cycles.

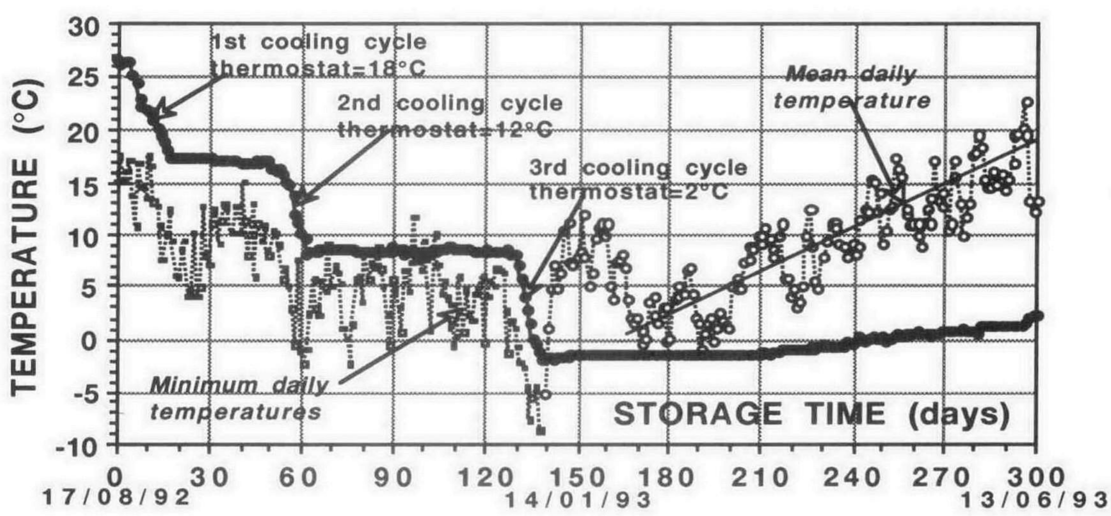

Fig. 5. Aeration of wheat in the experimental bin. Grain temperature in the centre of the bin. Minimum (period of cooling cycles) and mean (reheating period) daily temperatures

the operating cost of aeration in the case of the trial was 0.1 US$/t; that is to say less than with insecticides for an equal duration (300 days): 0.3 to 0.7 US$/t.

Conclusions

In temperate climates, aeration is the best technique to preserve grain whatever the quality criterion may be.

It has to be undertaken when the ambient temperature is close to the daily minimum, e.g. mostly in the night, and preferably with the fan sucking the air through the grain if the static pressure exceeds 2 kPa. There is no need for a chilling unit. A simple and properly adjusted thermostat is sufficient to provide automatic control and permit grain to cool from 30°C or more, to 4°C in 3 aeration cycles within 100 days. When grain is initially sound, 2 aeration cycles are sufficient to achieve 8–10°C and ensure safe storage for at least one year. These prescriptions have been confirmed by observations made on wheat stored in large round concrete bins (diameter 9 m, height 40 m, capacity 2000 t).

A properly designed and managed aeration facility decreases the operating cost of storage because (1) insecticide treatments are not needed and (2) the electricity tariff is cheaper at night, when the fans are used.

The slight rewetting of the grain (on top surface when sucking, above the ducts when blowing) is not a major drawback: a small 'turning over' of the grain in the storage bin eliminates the damp layers. Well cooled grain, naturally reheats very slowly in the springtime.

With regard to sanitation, mould growth is inhibited, pests are totally controlled without chemicals,which removes the risk of residues when selling, processing and consuming the grain.

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